JOURNAL OF SCIENTIFIC INSTRUMENTS

A MONTHLY PUBLICATION
DEALING WITH THE PRINCIPLES,
CONSTRUCTION AND USE OF SCIENTIFIC INSTRUMENTS

Produced by The Institute of Physics
with the co-operation of the National Physical Laboratory

EDITOR

H. R. LANG
A.R.C.S., PH.D., F.INST.P.
Secretary of The Institute of Physics

VOLUME 33

LONDON
THE INSTITUTE OF PHYSICS

JOURNAL OF SCIENTIFIC INSTRUMENTS

ADVISORY COMMITTEE

for year ending 30 September, 1956

H. Barrell, A.R.C.S., D.SC., F.INST.P., *Chairman*

C. B. Allsopp, PH.D., D.SC., F.INST.P., *Representing the British Institute of Radiology*

C. R. Barber, B.SC., F.INST.P., *Representing the National Physical Laboratory*

P. H. Bigg, B.SC., *Representing the National Physical Laboratory*

H. J. J. Braddick, B.A., PH.D.

S. S. Carlisle, M.SC.

Sir John Cockcroft, K.C.B., C.B.E., PH.D., D.SC., F.INST.P., F.R.S., *President, The Institute of Physics*

B. M. Crowther, M.A., PH.D., F.INST.P.

A. J. Dalladay, A.INST.P.

B. P. Dudding, M.B.E., A.R.C.S., PH.D., F.INST.P., *Honorary Secretary, The Institute of Physics*

K. M. Greenland, B.SC., PH.D., F.INST.P.

J. A. Hall, A.R.C.S., B.SC., PH.D., F.INST.P.

E. J. Harris, PH.D., D.SC.

P. S. H. Henry, B.A., PH.D., F.INST.P.

R. V. Jones, C.B., C.B.E., M.A., D.PHIL., F.INST.P., F.R.S.E.

D. M. C. MacEwan, B.SC., M.A., PH.D., A.INST.P.

M. C. Marsh, M.A., PH.D., F.INST.P.

J. D. McGee, M.SC., PH.D., F.INST.P.

K. A. G. Mendelssohn, M.A., D.PHIL., F.INST.P., F.R.S.

A. C. Menzies, M.A., D.SC., F.INST.P., *Representing the Physical Society*

F. Pasquill, PH.D., D.SC., *Representing The Royal Meteorological Society*

A. G. Peacock, B.SC., A.INST.P.

A. T. Pickles, O.B.E., M.A., F.INST.P.

G. H. Rayner, B.A., *Representing the National Physical Laboratory*

D. Taylor, M.SC., PH.D., M.I.E.E., F.INST.P.

S. Whitehead, PH.D., D.SC., M.I.E.E., F.INST.P. (died May 1956), *Honorary Treasurer, The Institute of Physics*

A. B. Wood, O.B.E., D.SC., F.INST.P., *Representing the Physical Society*

A. J. Young, B.A., B.SC.

CONTENTS OF VOLUME 33

JANUARY 1956

RIGINAL CONTRIBUTIONS

pers

PAGE
A scintillation counter for the assay of radioactive gases. By D. R. Stranks . . . 1
Some aspects in the design of a torque magnetometer. By F. W. Harrison . . . 5
A servo-mechanism for the study of self-extinction of gaseous discharges in cavities in dielectrics. By E. C. Rogers, E. B. Page and V. G. Harriss . . . 7
Some parasitic deflexions in parallel spring movements. By R. V. Jones and I. R. Young . . . 11
The stability of thermistors. By A. Beck . . . 16
A mechanical binary-decimal converter. By M. Setterwall . . . 18
The use of polarized light for the measurement of small angular displacements. By A. J. Bartley . . . 20
A laboratory scale chill-casting vacuum induction furnace. By D. A. Craw and W. G. Henry . . . 22
Apparatus for the electronic presentation of optical diffraction patterns. By A. W. Hanson and A. Menarry . . . 24
A constant temperature solubility cell or reaction vessel for a Beckman quartz spectrophotometer. By D. N. Glew and R. E. Robertson . . . 27
A wide range Schlieren system. By H. Jeffree . . . 29

aboratory and workshop notes

A simple desorption system for obtaining temperatures above that of liquid helium. By A. C. Rose-Innes and R. F. Broom . . . 31
A two-way tap for continuous operation. By F. A. Grimes 31
A thyratron index and time-marking unit. By R. B. Morrison . . . 32
A method of preparing laminated copper. By K. Nelson 33
A simple relay-operated timer. By L. R. Jenkin . . . 33
A magnetically operated vacuum valve. By R. M. Glaister . . . 34
An object holder for microscopic measurements. By H. Shapiro . . . 35
An adaptable mechanism for converting rotary motion into a succession of linear movements. By A. L. Sims 35

OTES AND NEWS

orrespondence

Transit time spread in electron multipliers. From T. D. S. Hamilton and G. T. Wright . . . 36
A capacitance-resistance hygrometer. From C. L. Cutting, A. C. Jason and J. L. Wood . . . 36
ew instruments, materials and tools . . . 37
otes and comments . . . 40

FEBRUARY 1956

RIGINAL CONTRIBUTIONS

apers

The temperature calibration of a high-temperature X-ray diffraction camera. By J. A. Brand and H. J. Goldschmidt . . . 41
A calorimeter for measuring energy absorption from pile radiation. By A. R. Anderson and R. J. Waite . . . 46
PAGE
The principles and apparatus of the injection system of the Birmingham proton synchrotron. By C. A. Ramm . . . 52
An isothermal micro-calorimeter. By J. B. Stott . . . 58
A cell for kinetic measurements of gas evolution from systems irradiated by fast electron beams. By C. B. Amphlett and T. F. Williams . . . 64
Small angle X-ray diffraction unit. By C. R. Worthington . . . 66
A wide range, recording, logarithmic photometer circuit. By P. Hariharan and M. S. Bhalla . . . 69
A fast multiple coincidence circuit. By B. Collinge, A. W. Merrison and D. Eccleshall . . . 72
The effect of humidity on the stability of inductance standards. By G. H. Rayner and L. H. Ford . . . 75
Fundamental behaviour of sensitive springs. By R. Tomaschek . . . 78

Laboratory and workshop notes

A simple universal X-ray camera stand. By M. D. Karkhanavala . . . 82
A sensitive manostat. By H. Tompa . . . 82
A simple air-lock for ionization gauges. By C. Barrow . 83
A portable β-γ radiation monitor. By B. W. Emmerson and S. P. Newbery . . . 83
A simple interval timer. By M. T. Lilburne and D. Shipley . . . 84
A four-point probe apparatus for measuring resistivity. By D. B. Gasson . . . 85

NOTES AND NEWS

Correspondence

Errors in the A.S.T.M. Index of X-ray powder diffraction patterns. From J. W. Hughes, I. E. Lewis and A. J. C. Wilson . . . 86
New instruments, materials and tools . . . 87
Notes and comments . . . 88

MARCH 1956

ORIGINAL CONTRIBUTIONS

Papers

An attachment for high-temperature single-crystal X-ray work. By L. S. Dent and H. F. W. Taylor . . . 89
An ultrasonic apparatus for recording the height of water waves in model ship tanks. By E. G. Richardson . 91
Devices for automatic potentiometric titration. By R. Audran and D. T. R. Dighton . . . 92
Some notes on the design and performance of X-ray proportional counters. By A. R. Lang . . . 96
An analysis of injection phenomena in the Birmingham proton synchrotron. By C. A. Ramm, R. F. Coe and T. B. Vaughan . . . 102
A precision high-temperature specimen chamber for an X-ray diffractometer. By G. K. Williamson and A. Moore . . . 107
A continuous-flow rotational viscometer for use with downward-settling suspensions. By G. F. Eveson and E. W. Hall . . . 110
A simple fast-recycling cloud chamber. By J. Walker, G. Tagliaferri, J. C. Bower and D. W. Hadley . 113
A simple theory for solid-backed bolometers. By L. M. Roberts and S. J. Fray . . . 115
A personal γ-radiation monitor with audible warning device. By D. Allenden and I. W. Collip . . . 120

A5119
48/1 new

PAGE

Laboratory and workshop notes

Large liquid-filled plastic lenses. By J. W. TELFORD and N. S. THORNDIKE 123
Measurement of the damping of metal bar specimens in mechanical resonance. By H. PURSEY and E. C. PYATT 123
A simple method of controlling the temperature of a prism. By K. P. NORRIS 125

NOTES AND NEWS

Correspondence

Correction of millimetre mercury barometers. From D. AMBROSE and P. H. BIGG 126
A liquid scintillator containing nitrogen. From J. R. PRESCOTT 126

New instruments, materials and tools 127

Notes and comments 128

APRIL 1956

ORIGINAL CONTRIBUTIONS

Papers

A magnetic spectrometer. By D. J. PROWSE and W. M. GIBSON 129
A water vapour recorder for equatorial use. By C. G. WEBB and A. RAJARATNAM 132
An automatic scanner for nuclear emulsions. By S. J. GOLDSACK and H. B. VAN DER RAAY 135
A versatile X-ray diffractometer for single-crystal and powder studies. By A. R. LANG 138
Application of the electrostatic precipitator to the measurement of radioactive aerosols. By B. A. BERGSTEDT . 142
An improved helium liquefier and cryostat. By D. F. BREWER and D. O. EDWARDS 148
A magnetic analyser for high energy particles. By A. LOVATI and H. TYRÉN 151
An instrument for measuring respiratory rates and volumes. By W. NISBET 154
A logarithmic megohmmeter. By P. HARIHARAN and M. S. BHALLA 158

Laboratory and workshop notes

Simple high-pressure closures and electrodes. By D. GUGAN 160
A simple gas valve. By J. FULLER 160
A sensitive null-point manometer. By J. P. BERRY . 161
Miniature diffraction cameras for micro-focus X-ray units. By J. B. FINEAN 161

NOTES AND NEWS

Correspondence

Rotating electrode unit for measurements of the electric strength of insulating liquids. From A. POWELL and K. H. STARK 163
Modifications of photomultiplier characteristics by dynode voltage control. From D. S. HOBBS; E. M. DEELEY . 163
A simple apparatus for recording the variation of Hall coefficient with temperature. From E. H. PUTLEY . 164

New instruments, materials and tools 165

Manufacturers' publications 166

Notes and comments 167

MAY 1956

ORIGINAL CONTRIBUTIONS

Papers

A large optical slit mechanism employing spring movements. By R. V. JONES 16
A remotely-controlled traversing yawmeter for boundary-layer exploration. By D. W. BRYER 17
Two designs for a paramagnetic oxygen meter. By A. HOBSON and R. H. KAY 17
A Pirani gauge for operation up to a pressure of 10 mm of mercury. By J. H. LECK and C. S. MARTIN . . 18
A modified bridge earthing device. By B. BERGER . . 18
An oxygen-quenched Geiger-Müller counter. By D. SRDOČ 18
An input amplifier for a pulse-height analyser. By A. FOLKIERSKI 18
A remote control apparatus for the movement of dosage measuring or similar equipment to indicated positions. By B. J. PERRY and N. H. PIERCE 19
Fine grain development in xerography. By K. A. METCALFE and R. J. WRIGHT 19
A switch-dial potential divider. By W. K. CLOTHIER . 19

Laboratory and workshop notes

A simple water failure guard for diffusion pumps and condensers. By G. HOUGHTON 19
The direct evaluation of psychrometric data from dry- and wet-bulb recorders. By I. F. LONG 19
Transfer of movement into a vacuum by means of twisting a copper tube. By H. VON UBISCH 20
A furnace over-temperature protection device. By R. J. NEWMAN 20
A beam splitter with illumination control. By P. M. FORSYTH and R. W. G. HUNT 20

NOTES AND NEWS

Correspondence

An automatic cathode-ray oscilloscope beam brightening device for transient recordings. From O. H. DAVIE; J. WOOD 20
A monitored Geiger-counter X-ray powder diffractometer with automatic recording. From J. W. HUGHES and E. R. PIKE 20
Calibration of a stroboscopic light. From T. F. FORD and T. G. ALEXANDER 20

New books 20

New instruments, materials and tools 20

Manufacturers' publications 20

JUNE 1956

ORIGINAL CONTRIBUTIONS

Papers

A proportional counter tube for X-ray diffraction analysis. By A. R. B. SKERTCHLY 20
Calorimetry by the method of mixtures. By D. W. PLESTER, S. E. ROGERS and A. R. UBBELOHDE . . 21
The measurement of frictional forces at vibrating contacts. By J. S. HALLIDAY 21
A wavelength discrimination spectrometer. By C. R. FORSHAW 21
An X-ray absorptiometer for the determination of tetraethyl lead in petrol. By J. F. BROWN and R. J. WEIR . 22

PAGE
simple monitor circuit for a spectrographic a.c. arc source. By D. F. T. Roberts and E. H. S. van Someren 226
semi-automatic pen-recorder chart analyser. By C. W. Spencer and G. H. Bazzard 228
calorimetric method of determining the energy output of radioactive materials. By A. G. White 230
general purpose electromagnet. By W. Sucksmith and S. P. Anderson 234
ringe spacing in interference microscopes. By F. R. Tolmon and J. G. Wood 236

oratory and workshop notes

simple visual method of accurately positioning a specimen relative to an X-ray beam. By P. J. Holmes and P. D. Fochs 239
n illuminator for detecting air lines in glass tubing. By S. J. Morrison and S. M. Phillipson 239
hin film abrasion tester. By J. C. Kelly 240
two-circle Geiger counter mounting. By R. Bones 241
high vacuum magnetic mercury cut-off. By R. A. W. Haul and E. R. Swart 243
control valve for corrosive liquids. By J. Hodkinson 244

TES AND NEWS

respondence

onduction-cooled vapour traps. From V. A. Heathcote 245
ngle-spring hinges. From R. V. Jones 245
n adaptable mechanism for converting rotary motion into a succession of linear movements. From P. Grodzinski 245

w instruments, materials and tools 246

tes and comments 248

JULY 1956

ECIAL ARTICLE

The language of instrument calibration and performance. By K. M. Greenland 249

RIGINAL CONTRIBUTIONS

pers

A method for rapid analysis of very small gas samples. By H. E. Lewis and O. C. J. Lippold 254
A simple differential pulse height analyser. By E. C. Park 257
A sensitive and stable nuclear induction head. By E. A. Richards, G. Phillips and W. K. Campe 260
A constant-volume, membrane, interferometric microrespirometer. By B. M. Turner 263
An instrument for the automatic recording of hysteresis loops. By D. C. Gall and J. D. Watson 265
The omegatron as a leak detector. By R. L. Bell 269
An apparatus for producing air of controlled relative humidity for hygrometer calibration and testing. By L. A. Cram 273
A high pressure methane ionization chamber. By F. J. M. Farley 276

boratory and workshop notes

Adaptation of a gas and water union to high vacuum circuits. By A. D. Cassell and D. A. Hockly 279
A parallel-spring cross-movement for an optical bench. By R. V. Jones 279
PAGE
The use of a ball-point recording system on the Dines anemometer. By E. A. Cohen 280
A light interrupter of continuously variable on-off ratio. By T. P. Brody 281
A dual-purpose specimen spinner for transmission and reflexion X-ray diffraction. By P. N. Bestelink and D. R. Holmes 281
A tapered plug vacuum valve. By H. R. Moore 282
The infra-red spectrometer as a non-dispersive instrument. By R. Burt and G. J. Minkoff 283

NOTES AND NEWS

Correspondence

A capacitance-resistance hygrometer. From J. MacDowall; C. L. Cutting, A. C. Jason and J. L. Wood 284

New books 285

New instruments, materials and tools 286

Notes and comments 288

AUGUST 1956

SPECIAL ARTICLE

The Physical Society's Exhibition—London, 1956. By A. J. Maddock 289

ORIGINAL CONTRIBUTIONS

Papers

An automatic device for fixing thick nuclear emulsion layers. By G. Thuro 296
Composite quarter- and half-wave plates. By W. H. J. Childs 298
A high-pressure diffusion cloud chamber in a pulsed magnetic field. By A. P. Batson, P. N. Cooper and L. Riddiford 302
Calibration of the specimen tilt device of the EM-3 electron microscope. By J. A. Gard 307
A "hodoscoped" cosmic-ray recorder. By J. C. Barton 308
Demagnetization of magnets due to contact with ferromagnetic bodies. By M. McCaig 311
A precision electrode-less conductance cell for use at audio-frequencies. By S. R. Gupta and G. J. Hills 313
A mechanical-electrical transducer of simple design. By M. Manzotti 314
A simple, small dielectric test cell for liquids. By S. Baxter and P. D. Wilmot 315

Laboratory and workshop notes

A McLeod gauge for measuring a wide range of pressures. By H. A. Wyllie 317
An automatic absolute reflectometer. By J. H. Jaffe and U. Oppenheim 317
A flexible mount for specimens in single crystal and powder X-ray cameras. By E. Aruja 318
A mercury cut-off for transferring gas at atmospheric pressure into a high vacuum. By N. N. Greenwood 318
Phasing device for small synchronous motors. By D. T. R. Dighton and W. G. Waters 319
A water-driven device for filling, aerating and agitating baths. By A. L. Sims 320
Laboratory furnace with rotating table for producing conducting glass. By E. Alexander and I. T. Steinberger 320

PAGE
A transducer for the sequential measurement of two levels of thrust. By J. G. CLOUSTON 321
A liquid level regulator for replenishing cold traps. By H. C. PROBYN 322
An easily constructed helium flow counter. By E. J. HARRIS 322

NOTES AND NEWS

Correspondence

Coulometric titrations using a pulse technique. From M. A. V. DEVANATHAN and Q. FERNANDO . . . 323
An improved photomultiplier construction. From A. E. JENNINGS and C. E. F. MISSO 323
A cloud chamber illumination unit. From Á. BARDÓCZ and Á. KLATSMÁNYI 324

Manufacturers' publications 325

New instruments, materials and tools 326

Notes and comments 328

SEPTEMBER 1956

ORIGINAL CONTRIBUTIONS

Papers

A portable temperature-chlorinity bridge for estuarine investigations and sea water analysis. By B. V. HAMON 329
The measurement of film thickness with a pneumatic hypodermic needle mechanism. By N. STOLOW . . 333
A semi-conducting antimony bolometer. By E. J. GILLHAM 338
A photoelectric microscope for the measurement of linear scales. By J. S. CLARK and A. H. COOK . . . 341
On preparing plastic copies of diffraction gratings; an extension to the Merton-N.P.L. process. By G. D. DEW 348
A microwave thermistor calorimeter. By M. J. SMITH and J. R. M. VAUGHAN 353
An instrument for measuring absorptivities for solar radiation. By H. TABOR and I. T. STEINBERGER . . 356

Laboratory and workshop notes

A d.c. arc chamber for radioactive materials. By F. T. BIRKS and R. P. THORNE 359
A gas introductor for a vacuum system. By H. A. WYLLIE 360
A method for comparing ultrasonic velocities in solids and liquids using a spectrometer. By G. M. SREEKANTATH and A. O. MATHAI 361
A modified flap-type vacuum valve. By H. M. BUCK . 361
Adhesives for galvanometer mirrors. By N. W. SULLIVAN 362
A microwave amplitude stabilizer. By S. J. FRAY and M. F. KIMMITT 363

NOTES AND NEWS

Correspondence

A simple bridge circuit for the accurate measurement of pulse impedance. From J. B. GUNN 364
Temperature controller for an electric furnace. From R. W. CHRISTY 365

New instruments, materials and tools 366

Notes and comments 367

OCTOBER 1956

SPECIAL ARTICLE

Fine measurements. By J. R. ADAMS 3

ORIGINAL CONTRIBUTIONS

Papers

A radioactive ionization gauge and its application to the measurement of latent heat of vaporization. By J. H. BEYNON and G. R. NICHOLSON 3
An alinement and co-ordinate system for nuclear emulsion stacks. By E. SILVERSTIEN and W. SLATER . . 3
A miniature eight-channel pressure recorder. By H. M. NELSON and G. A. PARKER 3
A high-temperature micro-thermostat for X-ray studies on single crystals of appreciable vapour pressure. By P. J. A. MCKEOWN 3
The application of pneumatic gauging to high precision linear measurement. By J. C. EVANS and I. G. MORGAN 3
A simple scanning mechanism for X-ray diffraction. By G. W. SMITH and R. M. HINDE 3
A simple vacuum leak detector using a radio-frequency mass spectrometer. By P. F. VÁRADI and L. G. SEBESTYÉN 3
An instrument for the continuous measurement of shrinkage of textile yarns. By R. A. E. ELLIS, K. W. HILLIER and A. B. THOMPSON 3
A portable instrument for respirable dust sampling. By R. J. HAMILTON 3

Laboratory and workshop notes

Preparation and maintenance of spherical metal electrodes in hydrogen. By J. O'M. BOCKRIS, B. E. CONWAY and W. MEHL 4
Conical ground joint extractor. By S. G. YORKE . . 4
A simple demountable vacuum seal for electrical connexions. By N. FUSCHILLO and J. GILVEY . . . 4
A micromanometer designed for recording. By G. W. E. ROBERTSON 4
An indium foil counter for the measurement of neutron flux. By D. H. PEIRSON and F. C. LOVELESS . . 4

NOTES AND NEWS

Correspondence

The use of octal numbers for recording binary-coded information. From G. W. HUTCHINSON . . . 4
Solarization technique for interferograms. From C. E. ARREGGER 4

New instruments, materials and tools 4

Notes and comments 4

NOVEMBER 1956

ORIGINAL CONTRIBUTIONS

Papers

An automatic electromechanical stressing unit for creep and fatigue testing. By A. J. KENNEDY and R. F. SLADE 4
An electrostatic null detector. By J. HART and A. G. MUNGALL 4
An electrical indicator for a mercury U-tube manometer. By A. E. HAWKINS 4
Eight-channel recording on $\frac{1}{4}$ in. magnetic tape with a stationary-tape playback. By J. C. BARTON . . 4
Simple equipment for a small low temperature laboratory. By R. F. BROOM and A. C. ROSE-INNES . . . 4
An instrument for the measurement of salinity in estuaries. By E. G. SANDELS 4

PAGE
fast coincidence system for the measurement of short ifetimes. By G. JONES and J. B. WARREN . . . 429
namometer for tensile testing of high polymers. By A. R. PAYNE and J. F. SMITH 432
electronic analogue of the saturated vapour pressure urve of water. By R. J. TAYLOR 436
all-glass reference electrode for molten salt systems. By J. O'M. BOCKRIS, G. J. HILLS, D. INMAN and L. YOUNG 438
heart pulse amplifier and ratemeter. By D. G. WYATT 440

ratory and workshop notes

window material for high temperature X-ray cameras. By A. G. PROVAN, B. A. SHAW and G. I. WILLIAMS . 445
n internally metallizing a betatron toroid by vacuum deposition. By K. R. ALLEN, F. ASHWORTH and G. SIDDALL 445
simple rotary film evaporator. By B. B. MARSH and P. M. NOTTINGHAM 446
n improved design of radio-frequency ion source. By H. R. ALLAN and N. SARMA 447
secondary microwave attenuator. By H. A. PRIME . 448
egulator for maintaining a constant gas flow through a restriction of variable resistance. By E. F. KEEN and P. L. PALMER 449
n apparatus for the production of controlled lesions in biological tissue without stimulation. By G. E. KAUFER 450
he output resistance of a switch-dial potential divider. By R. W. WILLIAMS 451
method of storing mechanically fragile specimens for examination. By C. A. TREMLETT 451

TES AND NEWS

v books 452
v instruments, materials and tools 454
tes and comments 456

DECEMBER 1956

ECIAL ARTICLE

Some principles of measurement and control. By J. F. COALES 457

RIGINAL CONTRIBUTIONS

A new vacuum plate-camera of large capacity. By L. N. D. LUCAS and P. B. SEWELL 465
PAGE
An automatic analyser of uranium content in process streams. By H. BISBY, L. H. BROWN and D. R. CHAPMAN 467
On the reduction of the dark current of photomultipliers. By ZS. NÁRAY 476
A Kösters-type interferometer. By C. F. BRUCE . . 478
A simple direction-sensitive phototransistor circuit for use in optical pulse-counting systems. By W. T. BANE and D. L. A. BARBER 483
A simple method for the measurement of high-resistance values. By A. E. HAWKINS 486
Precision measurement of small radii of curvature. By R. N. WILSON 487
An improved ionization gauge control circuit. By P. HARIHARAN and M. S. BHALLA 488
A double-beam microspectrometer. By G. H. HAGGIS . 491
Temperature cycle controller. By J. C. BARNES . . 494
Measurement of the optical density of smoke in a chimney. By A. LITTLEWOOD 495
A mechanical Gardner mobilometer. By J. E. ROBERTS, A. J. TAYLOR and D. E. WOODS 499
The generation of accurate cylinders. By D. A. DAVIES . 501

Laboratory and workshop notes

The magnifying powers of optical instruments. By D. A. RICHARDS 503
The adaption of a metallurgical microscope to the "light profile" method. By H. MYKURA 504
A note on joining tungsten wire to other metals. By K. F. CHACKETT, P. REASBECK and D. G. TUCK . . . 505
A reversible message register. By C. J. SUMNER . . 505
Quantitative application of the Foucault test to objective lenses. By P. HARIHARAN 506
Device for measurement of tangents. By A. R. KING . 506

NOTES AND NEWS

Correspondence

Fringe spacing in interference microscopes. From J. W. GATES 507
Temperature and pressure measurement in an over-compression cloud chamber. From D. W. HADLEY, J. C. BOWER and J. WALKER 507
New instruments, materials and tools 508
Manufacturers' publications 511
Notes and comments 512
INDEX TO VOLUME 33 513

ORIGINAL CONTRIBUTIONS

A scintillation counter for the assay of radioactive gases

By D. R. Stranks, M.Sc., Ph.D., Chemistry Department, University of Leeds

[*Paper received* 19 *August*, 1955]

A glass chamber, with a plastic scintillator serving as one wall, may be used to assay gaseous samples of weak β-emitting nuclides (notably ^{14}C). The specific activities of duplicate samples can be reproduced to $\pm 0 \cdot 5\%$. Since the observed counting rate of an active gas sample is independent of gross impurities and the chemical form of the nuclide, sample preparation is simpler and faster than for other gas-counting methods. The scintillation counter assembly can be readily adapted to the assay of both liquid and solid samples; the method described for liquid assays has certain advantages over existing methods.

routine, precision assay of weak β-emitting nuclides,
ially ^{14}C, presents considerable problems. In many
ical applications the isotopic species may be isolated as
lid and then counted under an end-window Geiger,
illation or flow-type proportional counter. The repro-
bility of such an assay method is largely determined by
preparation of the solid samples; a reproducibility of
1% requires considerable manipulative skill. Diffi-
es due to sampling largely disappear if the β-emitter can
ssayed as a liquid. When mixed with a suitable scin-
or solution, liquids containing ^{14}C can be assayed to a
precision and with a high detection efficiency.(1) How-
, this method is limited to compounds which do not
ch or absorb fluorescence of the scintillator and which
miscible with the scintillator solution. Alternatively,
compounds may be dissolved in a low vapour-pressure
ent and counted in a flow-type proportional counter.(2)
ough this method is more flexible than the former, it is
ted to involatile solutes and has a low detection
iency (approximately 1%).

he assay of gases is the most convenient means of achieving
reproducibility in sample preparation, but counting in
Geiger, proportional or ion-chamber region is applicable
to those gases which have suitable ionization charac-
stics; such counting methods are also critically dependent
the purity of the gases to be assayed. These restrictions
ld no longer be applicable if the radioactivity of a gas
e detected by virtue of the scintillations produced in a
d scintillator within the gas vessel. An assay method
ed on this principle was first attempted by Hanle, Hengst
Schneider(3) who deposited a layer of anthracene crystals
one wall of a gas chamber and detected scintillations due
$^{14}CO_2$ with a conventional photomultiplier counter
mbly. Unfortunately solid anthracene readily evaporates
a vacuum and is thus inherently unstable in such an
angement. Moreover, cooling of the photomultiplier
e, in order to reduce the high thermal background, caused
radioactive gas to be adsorbed on the solid scintillator.
spite such difficulties, an assay method based on the
lication of these ideas appeared to offer promising
sibilities.

ommercial supplies are now available of plastic scin-
ators which are stable in a vacuum, chemically inert and
dily fabricated into various shapes. Accordingly, it
peared desirable to develop a gas-counting method based
the use of such scintillators in combination with a modern
h-gain, low-background photomultiplier tube. The
ults of this investigation, reported below, indicate that plastic scintillators may have distinct advantages in the assay of both radioactive gases and liquids.

EXPERIMENTAL

The plastic scintillator employed in this investigation was a commercial product (Pamelon made by Isotope Developments Ltd.) supplied as a $1\frac{1}{2}$ in. diameter cylinder. Slices of the scintillator were cut on a lathe and polished with commercial Perspex polishes. Scintillations were detected by an eleven-stage photomultiplier tube (type 6097A by Electric and Musical Industries Ltd.) with an earthed photocathode and using a circuit based on that of Owen.(4) Pulses from the photomultiplier were amplified by a cathode follower (gain $0 \cdot 1$ times) and linear amplifier, type 1049B (gain variable in 2 dB steps from 200 times to 20 000 times, i.e. 40 dB), discriminated by a single-channel pulse analyser, type N/101 and counted on a scaling unit, type 1009D. The regulated high voltage supply to the photomultiplier was drawn from a high voltage unit and potentiometer, type 1007B (stabilized $0 \cdot 1\%$ for 10% input variation) the input of which was drawn from a constant voltage transformer (stabilized 1% for 15% input variation).

The photomultiplier was mounted inside an aluminium light-tight box fitted with a sliding door which, when completely shut, activated a micro-switch and closed the high tension circuit of the photomultiplier. Refrigerants to cool the photocathode were contained in an annular brass vessel enclosing the photomultiplier tube. The whole assembly was enclosed in a set of demountable lead bricks $1\frac{1}{2}$ in. thick and housed in a special room, the temperature of which was maintained at 25 ± 1° C.

For normal counting the photomultiplier was operated at 1760 V and the additional amplification required for the counting of pulses obtained by variation of the attenuation in the linear amplifier. Since the pulse spectra of all the β-active sources employed in this investigation exhibited no sharp peaks, the pulse analyser was operated as a discriminator at a fixed potential of 20 V. (A peak was observed in the β-spectrum of ^{137}Cs, but the resolution was worse than is obtained with NaI(Tl) crystals.) The variation of counting rate with increasing amplification (i.e. decreasing attenuation) was measured for a series of β-emitters of widely-differing maximum energies and is illustrated by typical curves in Fig. 1. It is seen that these curves are characterized by a plateau region, in which all genuine scintillations are being recorded, followed by a region in which multiple pulses are observed. For weak β-emitters this plateau is somewhat ill-defined, since the amplification required to detect all the scintillations due to such emitters is close to the region of multiple counts. The amplification necessary to produce multiple counts was slightly greater, the lower the incident β-particle energy. (It is interesting to note that the attenuation curve for gaseous ^{14}C compounds is steeper than that for solid ^{14}C compounds. The difference is attributed to absorption of very low energy β-particles in the air space between the scintillator disk and the solid sample; the gas-counting method on the other hand will detect a considerable fraction of these particles.) The multiple counts may be due either to after-pulsing in the photomultiplier tube(5) or to the occurrence of satellite light peaks in the plastic scintillator.(6,7). At present it has not been possible to distinguish unambiguously between these two causes. While the multiple counts are quite reproducible, routine counting operations were conducted in the plateau region. The following instrumental settings were thus found convenient for the assay of β-emitters:

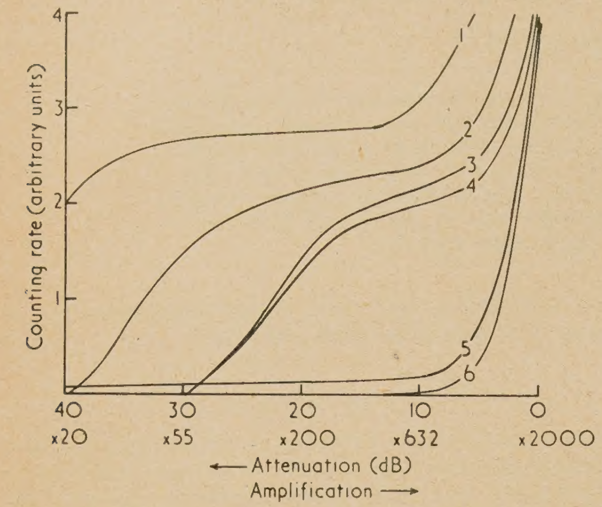


Fig. 1. Typical attenuation curves for β-active sources

Curve 1, UX_2, 2·32 MeVβ; curve 2, ^{36}Cl, 0·714 MeVβ; curve 3, ^{14}C, 0·154 MeVβ (as $^{14}CO_2$); curve 4, UX_1, 0·205 MeVβ; ^{35}S, 0·167 MeVβ; ^{14}C (as $Ba^{14}CO_3$); curve 5, total background; curve 6, thermal noise.

photomultiplier:	1760 V;
linear amplifier:	16 dB attenuation. (Overall gain of 320 times); 0·8 or 250 μs differention time; 0·08 μs integration time;
discriminator:	20 V.

Under these conditions a 3 mm scintillator slice exhibited a background of 20 counts/min, of which no more than 3 counts/min were due to thermal noise in the photomultiplier. It is common practice in scintillation counting to cool the photomultiplier tube to reduce thermal emission and hence the background count. In the present instance, since thermal emission represents but a small fraction of the total background, it was unnecessary to introduce this additional complication. When the present tube was cooled to −80 or −170° C, the total background, as measured under the standard counting conditions, actually increased some 2% due to the increased fluorescence efficiency of the scintillator at the lower temperatures. However, if it is desired to operate at higher amplifications to achieve higher counting rates from a β-active sample (see below), cooling of the p cathode may be desirable since thermal emission then sents a considerable fraction of the total background c

PROCEDURE FOR GAS COUNTING

A 3 mm slice of scintillator *S* is attached with Ap grease "N" to the ground-glass flange of the chamber (v 10·86 cm³) at point *G* as shown in Fig. 2. Tests showe it was unnecessary to silver the lower surface of the tillator since complete internal reflexion of a conside fraction of the scintillations occurs at the plastic-air inte The chamber is attached by the standard B7 joint *J* conventional vacuum system and evacuated to a pressu 10^{-4} mm of mercury. The radioactive gas is then adm from a reservoir to a known pressure, as measured on a bore mercury manometer. Alternatively, if required, sample may be quantitatively frozen into the chamb application of a refrigerant at the "cold finger" *C*. chamber is next positioned in the Perspex source hold and two drops of paraffin oil are added to the top o scintillator at point *P* before the chamber is spring-lo against the photomultiplier window. Under normal ditions, when cooling of the photocathode is unnecessary, sample can be counted immediately. The preparation sample for counting by this procedure requires only minutes. After counting, the gas sample is pumped of storage, the chamber flushed with an inactive gas and pum for ten minutes at a pressure of 10^{-4} mm of mercury. chamber is now ready for admission of a new gas sampl for checking of the background.

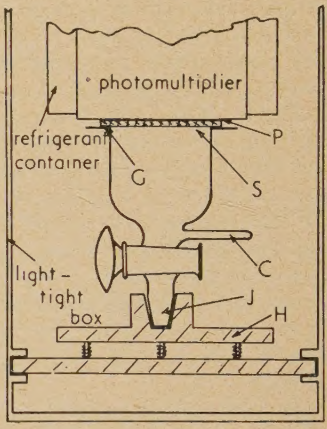


Fig. 2. The scintillation gas-counter assembly

^{14}C compounds. The gas-counting method was stu with respect to $^{14}CO_2$ as follows. The counting cha was filled with increasing pressures of highly active ^{14}C up to 20 mm of mercury such that the maximum coun rate was 40 000 counts/min. Since the counting rate accurately proportional to the pressure of $^{14}CO_2$ (curve Fig. 3) no coincidence losses can occur up to this high coun rate at least. However, at higher pressures of up to atmosphere of low-activity $^{14}CO_2$, the observed count rate was not directly proportional to the gas pressure (curv Fig. 3). Furthermore, with a fixed pressure of $^{14}CO_2$ increasing pressures of inactive carbon dioxide, the obser activity decreases in precisely the same fashion [e.g. at 20 of mercury of $^{14}CO_2$, the counting rate is 13·6% lower t

expected (the dashed curve of Fig. 3); with inactive on dioxide at the same total pressure, the observed nting rate of a $^{14}CO_2$ sample is reduced 13·8% from at the extrapolated zero pressure]. The effect may thus attributed to self-absorption of β-particles in the gas se. It is apparent that the specific activities of gas samples different pressures must be corrected for this self-absorption ect. It is interesting to note that this self-absorption can be scribed by an exponential relation, as is the case for self-sorption in solids.(8) Thus if A_p, A_0 are the specific ivities of a gas sample at carbon dioxide pressures of p d 0 cm of mercury respectively, then:

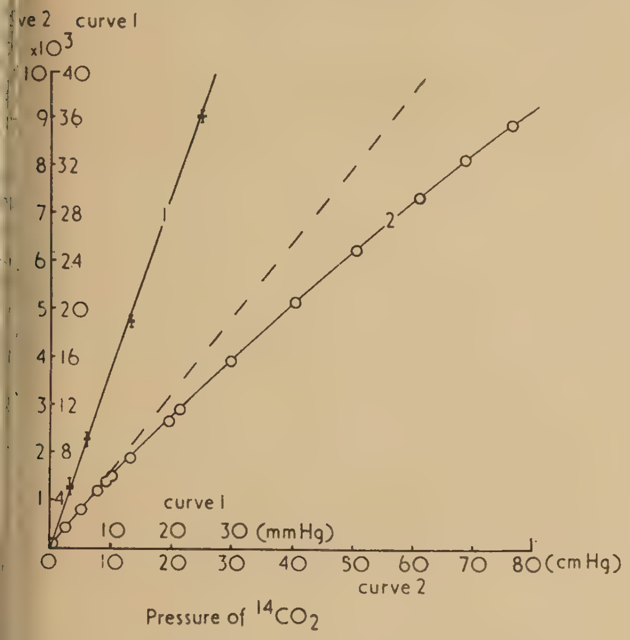


Fig. 3. Variation of counting rate with gas pressure

$$A_p = A_0 \exp(-\mu p)$$

ere $\mu = 6 \cdot 33 \times 10^{-3}$ (cm of mercury)$^{-1}$.

To test the reproducibility of the counting method, duplicate nples of $^{14}CO_2$ were each counted to a total of 50 000 counts . to a standard deviation of 0·44%). The specific activities duplicates (expressed as counts per min per cm of mercury) uld then be reproduced to ±0·5%, provided the high nsion supply was adequately stabilized as described above d the temperature of the counting assembly was regulated ±1° C. During a single day the overall sensitivity of the unting assembly may drift up to 2%. To maintain a producibility of ±0·5%, it is essential to refer all specific tivities to a standard sample.

The sensitivity of the method was determined with a ndard ^{14}C polymethyl methacrylate source supplied by the adiochemical Centre, Amersham. This source has a ecific activity of 10·2 μc/g when compared with the ational Bureau of Standards (Washington) reference source. ne polymer source was combusted in a microchemical rnace, the $^{14}CO_2$ collected in barium hydroxide and the sultant barium carbonate decomposed with lead chloride in vacuum. The counting chamber was filled with samples of is carbon dioxide and the observed counting rates corrected r self-absorption. The counter efficiencies at various attenuations are recorded in Table 1, together with the respective background counts.

Table 1. *Efficiency of gas counter for* ^{14}C

Attenuation (dB)	*Counter efficiency (%)*	*Background (counts/min)*
16	9·7	20
14	10·9	28
12	12·8	44
10	14·7	56
8	17·9	80

Since the scintillator disk occupies 15·8% of the total area of the chamber interior, the maximum counting efficiency ought not to exceed 15·8%; but efficiencies greater than this value will occur in the region of multiple counts, i.e. at attenuations of eight or less.

The observed counting rate of a $^{14}CO_2$ sample was completely unaffected by traces of electro-negative impurities (water, oxygen, nitrogen oxides, etc.) which in proportional or Geiger gas-counting could not be tolerated. Indeed, samples of $^{14}CO_2$ can be assayed in the presence of large pressures of other gases, since the only effect of such gases is to cause absorption of β-particles of the same magnitude as the self-absorption by carbon dioxide itself. Thus high vacuum equipment is not essential for this present method and trial assays have been successfully performed with a rotary mechanical vacuum pump and even with a water filter pump. Samples of $^{14}CO_2$ have also been assayed when aspirated into the counting chamber with air; such a method may be directly applicable to biological respiratory investigations.

Unlike other gas counting methods the chemical form of the isotopic species is immaterial, provided no reaction occurs with the plastic scintillator. Compounds of ^{14}C have been assayed as carbon dioxide, carbon monoxide, hydrogen cyanide, cyanogen and carbon oxysulphide.

^{36}Cl compounds. 1 ml. aliquots of an aqueous solution of $K^{36}Cl$ were converted to either chlorine or hydrogen chloride, condensed into the chamber and counted. The activity of the chlorine sample was 3080 ± 32 counts/min and that of the hydrogen chloride sample 3069 ± 43 counts/min, indicating that the chemical form of the isotope is inconsequential. Assuming the specific activity of the potassium chloride sample to be 1 μc/g, Table 2 gives the counter efficiencies for ^{36}Cl (as a gas) determined at various attenuator settings.

Table 2. *Efficiency of gas counter for* ^{36}Cl

Attenuator (dB)	*Counter efficiency (%)*	*Background (counts/min)*
16	13·7	20
14	14·5	28
12	14·7	44
10	16·4	56
8	23·8	80
6	53·5	130

The routine assay of ^{36}Cl as chlorine gas is not recommended as chlorine is adsorbed very strongly on the plastic scintillator and memory effects are considerable; assay of ^{36}Cl as hydrogen chloride is thus preferable. In the latter case it is advisable to add concentrated sulphuric acid and manganese dioxide to a solid, rather than an aqueous, sample of a chloride since absorption of hydrogen chloride in water droplets, condensed within the chamber, can be troublesome.

PROCEDURE FOR LIQUID COUNTING

The demountable counting assembly is inverted. A polished dish of effective volume 2·5 ml. is fabricated from a Pamelon cylinder. The radioactive liquid is pipetted directly into this dish which is placed with a little paraffin oil on top of the photomultiplier window. The sample is then counted as above. [All liquid-counter efficiencies were determined under the instrumental settings listed earlier, i.e. in the "pleateau" region in which all genuine pulses are recorded. The functional variation of counter efficiencies with amplifier attenuations will be as quoted in Table 1 (for ^{14}C and ^{35}S) and in Table 2 (for ^{36}Cl and ^{40}K).] After counting, the scintillator dish is rinsed three times with distilled water to restore the natural background (45 counts/min). The reproducibility of the method is $\pm 0{\cdot}5\%$ provided the liquid aliquots are dispensed with a comparable accuracy.

^{14}C compounds. Samples of $^{14}CO_2$ were absorbed in sodium hydroxide and the solution pipetted on to the scintillator dish. Although a 1 ml. aliquot is sufficient to ensure "infinite-thick" samples, 2 ml. aliquots were normally employed for ease in manipulation. The absolute counting efficiency, as determined with the standard $^{14}CO_2$ sample, was 0·70% under the standard counting conditions. Provided the density of the solution remains unaltered, the observed counting rate of a liquid sample is independent of added inert salts. Coloured salts or dyes which absorb in the spectral emission region of the scintillator (e.g. copper sulphate, sodium dichromate, methyl orange) also have no measurable effect on the observed activity of a sample. A sample of $K^{14}CN$ was assayed as aqueous solutions of potassium cyanide, potassium cyanate, potassium thiocyanate, potassium argentocyanide and potassium hexacyanocobaltiate; within experimental error, all solutions exhibited the same counting rate.

^{35}S compounds. Aqueous solutions of $K^{35}SCN$ were assayed under similar conditions as the ^{14}C compounds. The counting rate of a sample was unaffected by added salts and the counting efficiency was of the order of 0·7%.

^{36}Cl compounds. Aqueous solutions were assayed as $K^{36}Cl$ with an efficiency of 18·6% compared to the efficiency of a skirted-wall Geiger tube of 3·6%. Aliquots of 2·5 ml. were necessary to ensure "infinite-thick" samples.

^{40}K compounds. A 2 ml. aliquot of saturated natural potassium chloride solution was counted with an efficiency of 29·3% compared to the efficiency of a skirted-wall Geiger tube of 7·8%.

PROCEDURE FOR SOLID COUNTING

A 3 mm scintillator disk is attached with a film of paraffin oil to the photomultiplier window and a conventional slotted solid-source holder positioned underneath. Solid sources are prepared according to standard radiochemical procedures, inserted on a tray in the source holder and counted under the standard conditions. Like all assay methods based on solids, this method is limited by the difficulty of reproducible sample geometry. Nevertheless, the method has two advantages over the normal end-window Geiger counting method:

(i) with weak β-emitters, the absence of a window (normally 2 mg/cm^2 thick) increases the detection efficiency by a factor of almost two;

(ii) a solid source subtends a larger solid angle a plastic scintillator disk (37·5 mm diameter) than window of a normal Geiger tube (e.g. 22 mm dia for a type EHM2 tube).

Thus a $Ba^{14}CO_3$ precipitate can be counted with an effic of five times that of an end-window type EHM2 tube. efficiency of a flow-type proportional counter (app mately 48%) is much higher than that of the present tillation counter (3·5%), but the former is somewha convenient for routine assays (e.g. the effect of static ch on precipitates, the purity of the flow-gas, etc.).

DISCUSSION

The major advantages of the present gas-counting me are the complete insensitivity to the chemical form o isotopic species and to trace impurities, the consequent and reduced time for sample preparation and the reproducibility. The absolute counting efficiency of a 16% is less than that of other gas counting methods, w approach 100% efficiency. However, if a higher effic were required, the complete gas chamber could be fabri from the plastic scintillator to achieve an efficienc approximately 100%. For low activity samples, oper in the "multiple counts" amplification region could lowe detection limit of current scintillation counters by a f of at least two.

Likewise, the chief advantages of the liquid co method are the insensitivity to the chemical form of isotopic species and to added salts, coloured or colou and the good reproducibility. Whilst the counting effici for ^{14}C is low (0·7%), it is nevertheless comparable to efficiencies of an end-window Geiger counter (of the c of 1%) and the counting of liquids in a flow-type pro tional counter (1%). Therefore it is suggested that method of liquid counting with a plastic scintillator dish very convenient routine assay method for ^{14}C.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. S. Walker for techn assistance. Thanks are also due to Imperial Chem Industries Ltd. for financial assistance and the loan apparatus.

REFERENCES

(1) Audric, B. N., and Long, J. V. P. *J. Sci. Instrum.,* p. 467 (1953).

(2) Schwebel, A., Isbell, H. S., and Meyer, J. D. *J. Nat. Bur. Stand.*, **53**, p. 221 (1954).

(3) Hanle, W., Hengst, K., and Schneider, H. *Z. Na forsch.*, **76**, p. 633 (1952).

(4) Owen, R. B. *Atomics [London]*, **4**, p. 34 (1953).

(5) Mueller, D. W., Best, G., Jackson, J., and Singlet J. *Nucleonics*, **10** (6), p. 53 (1952).

(6) Bittman, L., Furst, M., and Kallmann, H. *Phys. R* **87**, p. 83 (1952).

(7) Harrison, F. B. *Nucleonics*, **12** (3), p. 24 (1954).

(8) Calvin, M. *Isotopic Carbon*, p. 29 (New York: J Wiley and Sons Inc., 1949).

Some aspects in the design of a torque magnetometer

By F. W. Harrison, B.Sc., Ph.D., Grad.Inst.P., Mullard Research Laboratories, Salfords, Surrey

[*Paper first received* 1 *July, and in final form* 21 *September*, 1955]

The magneto-torsional system of a torque magnetometer is shown to be unstable if the torsion constant of the suspending wire is not chosen correctly. The way in which this fact limits the sensitivity of the apparatus is indicated.

he investigation of magnetic anisotropy in ferromagnetics y measurement of the torque produced on a specimen in a gh magnetic field is well known. The method has been used y many workers for determining the anisotropy constants f single crystals of ferromagnetic metals and alloys, and for e study of preferred orientation in fabricated polycrystalline rromagnetic materials.

The relation between the magnetocrystalline anisotropy nergy of a specimen and the torque produced upon it is pproximately

$$L = -dF_c/d\alpha$$

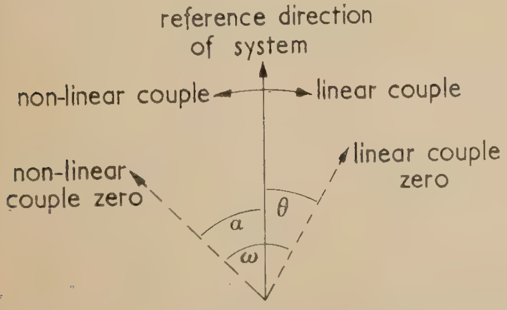
here L = torque per unit volume of the specimen,
F_c = magnetocrystalline anisotropy energy, and
α = angle between the magnetic field direction and a preferred crystallographic direction.

If the torque is measured on a uniformly magnetized pecimen, e.g. a spheroid, about the normal to a simple rystallographic plane and the crystallographic reference irection is a major axis, then the expression for L is easily erived from the known F_c in terms of the angle α and the nisotropy constants K_4 and K_6 (using the notation of toner⁽¹⁾). A torsion wire usually serves to measure L as varies from 0 to 180°. The anisotropy constants are then erived from the measured values of the torque.

It has been pointed out by Webster⁽²⁾ that the magneto-orsional system of the measuring apparatus will be unstable nless a sufficiently stiff torsion wire is used. The limiting orsion constant of the wire required for stability is calulated in this paper.

INSTABILITY OF THE MAGNETO-TORSIONAL SYSTEM

The torque magnetometer is an example of a system omprising a non-linear deflecting couple and a linear estoring couple. Instability can occur in such systems if he non-linear deflecting couple, expressed as a function of he angle of deflexion, possesses a maximum value, for increase in the angle of deflexion from some equilibrium position may then produce a decrease in the deflecting couple larger than that in the restoring couple.



Relative positions of the linear and non-linear couples, and their angular parameters

The requirement for stability is most readily evaluated from the total energy of the system. Suppose the non-linear couple to be represented by $f(\alpha)$ and the linear couple by $k\theta$, where α and θ are the angular parameters of each respectively as shown in the figure.

Let the work done against the non-linear couple in producing the deflexion α be $E(\alpha)\left[=\int_0^\alpha -f(\alpha)d\alpha\right]$ whilst that done against the linear couple is $\int_0^\theta k\theta . d\theta = \frac{1}{2}k\theta^2$.

The total energy of the system is then

$$E_T = E(\alpha) + \tfrac{1}{2}k\theta^2$$
$$= E(\alpha) + \tfrac{1}{2}k(\omega - \alpha)^2 \tag{1}$$

Supposing ω to remain fixed, the system is in equilibrium if $dE_T/d\alpha$ is zero, and this equilibrium is stable if $d^2E_T/d\alpha^2$ is positive.

$$\frac{dE_T}{d\alpha} = \frac{dE(\alpha)}{d\alpha} - k(\omega - \alpha) \tag{2}$$

$$\frac{d^2E_T}{d\alpha^2} = \frac{d^2E(\alpha)}{d\alpha^2} + k \tag{3}$$

For stability therefore $\dfrac{d^2E(\alpha)}{d\alpha^2} + k > 0$

or, since $E(\alpha) = \displaystyle\int_0^\alpha -f(\alpha)d\alpha$,

$$-\frac{df(\alpha)}{d\alpha} + k > 0 \qquad k > \frac{df(\alpha)}{d\alpha} \tag{4}$$

Applying this condition to the torque magnetometer, $f(\alpha) = LV$, where L is the torque per unit volume and V the volume of the specimen, and $k = \tau$, the torsion constant of the suspending wire,

$$\tau > \frac{VdL}{d\alpha} \quad \text{or} \quad \frac{\tau}{V} > \frac{dL}{d\alpha} \tag{5}$$

Thus for measurement of the torque curve under stable conditions τ must be chosen so that τ/V is greater than the maximum positive slope of the curve.

MAXIMUM SENSITIVITY OF THE TORSION WIRE

It is of importance to note the restriction set on the angular sensitivity of the torsion suspension due to the limitation on τ.

If L_{max} is the maximum torque per unit volume of the specimen then $L_{max}V$ is the maximum torque to be measured which is equal to $\tau\theta_{max}$ where θ_{max} is the maximum angular twist of the torsion wire.

Since for a stable system τ must be greater than $V(dL/d\alpha)_{max}$, where $(dL/d\alpha)_{max}$ is the maximum positive slope of the torque curve, then

$$\frac{L_{max}V}{\theta_{max}} > V\left(\frac{dL}{d\alpha}\right)_{max}$$

and

$$\theta_{max} < L_{max}\Big/\left(\frac{dL}{d\alpha}\right)_{max} \qquad (6)$$

Thus, since the maximum reading of the angle of twist of the torsion wire obtainable under stable conditions is independent of the volume of the specimen, the angular sensitivity cannot be increased by increasing the size of the specimen.

EVALUATION OF θ_{max} IN INDIVIDUAL CASES

It is of interest to determine numerical values for θ_{max} for the more important crystal orientations, namely those where the torque is measured in the (100), (111) and (110) planes in the cubic system and the planes containing the hexagonal axis in the hexagonal system.

L_{max} and $(dL/d\alpha)_{max}$ are obtained from the analytical expressions for the torque curves as follows:

(*a*) *Cubic system.* Torque curve expressions are taken from Bozorth,(3)

(i) (100) plane

$$L = (-K_4/2)\sin 4\alpha \qquad (7)$$

where α is measured from the [001] direction.

$$dL/d\alpha = (-K_4/2)\,4\cos 4\alpha \qquad (8)$$

L_{max} is thus $K_4/2$ whilst $(dL/d\alpha)_{max}$ is $2K_4$. θ_{max} must be therefore less than $\dfrac{K_4/2}{2K_4}$

or $< \frac{1}{4}$ radian.

(ii) (111) plane

$$L = (-K_6/18)\sin 6\alpha \qquad (9)$$

where α is measured from the $[1\bar{1}0]$ direction.

$$dL/d\alpha = (-K_6/3)\cos 6\alpha \qquad (10)$$

$L_{max} = K_6/18$ whilst $(dL/d\alpha)_{max} = K_6/3$. θ_{max} must be less than $\frac{1}{6}$ radian.

(iii) (110) plane

$$L = -\left[\frac{K_4}{8}(2\sin 2\alpha + 3\sin 4\alpha) + \right.$$
$$\left. + \frac{K_6}{64}(\sin 2\alpha + 4\sin 4\alpha - 3\sin 6\alpha)\right] \qquad (11)$$

where α is measured from the [001] direction.

$$\frac{dL}{d\alpha} = -\left[\frac{K_4}{8}(4\cos 2\alpha + 12\cos 4\alpha) + \right.$$
$$\left. + \frac{K_6}{64}(2\cos 2\alpha + 16\cos 4\alpha - 18\cos 6\alpha)\right] \qquad (12)$$

Since these expressions prove somewhat intractable if treated rigorously, it is convenient to assume that the term in K small compared with that in K_4.

$$\text{Then } L \simeq -(K_4/8)(2\sin 2\alpha + 3\sin 4\alpha)$$
$$dL/d\alpha \simeq (-K_4/8)(4\cos 2\alpha + 12\cos 4\alpha)$$
$$L_{max} \simeq 0{\cdot}56\,K_4$$

$(dL/d\alpha)_{max} \simeq 1{\cdot}52\,K_4$ if K_4 is positive or $-2K_4$ if K negative. θ_{max} must be less than 0·37 radian or 0·28 ra respectively.

(*b*) *Hexagonal system.* For a hexagonal crystal isotr in the basal plane the magnetocrystalline anistropy en can be expressed as $F_c = K_2'\sin^2\psi + K_4'\sin^4\psi$ (using notation of Stoner(1)) where ψ is the angle between hexagonal axis and the magnetization direction, or the direction in high fields.

In planes of type (*hki*0), i.e. those passing through hexagonal axis, the torque can be expressed as a si function of ψ thus:

$$L = -dF_c/d\psi = -\,[(K_2' + K_4')\sin 2\psi - (K_4'/2)\sin 4\psi]$$
$$dL/d\psi = -\,[(K_2' + K_4')2\cos 2\psi - 2K_4'\cos 4\psi]$$

To simplify the mathematical treatment let us assume t the term in K_4' is small compared with that in $(K_2' +$ For example, in the case of cobalt $K_4' \simeq \frac{1}{4}K_2'$.

$$\text{Then} \quad L \simeq -(K_2' + K_4')\sin 2\psi$$
$$dL/d\psi \simeq -2(K_2' + K_4')\cos 2\psi$$

giving

$$L_{max} \simeq (K_2' + K_4')$$
$$(dL/d\psi)_{max} \simeq 2(K_2' + K_4')$$

θ_{max} must be less than $\frac{1}{2}$ radian.

Thus in the above examples θ_{max} is independent of anisotropy constants of the specimen.

CONCLUSION

It has been shown that in the design of a torque magne meter a limit is set on the choice of torsional constant of suspending wire if instability of the system is to be avoid

This limit in turn restricts the maximum sensitivity of torsion head in such a way that it is independent of volume of the magnetic specimen used, and in the examp evaluated, independent of the anisotropy constants of specimen.

ACKNOWLEDGEMENTS

I am indebted to Dr. K. Hoselitz for drawing my attent to this problem and to Mr. R. F. Pearson for help discussions.

I wish to thank the management of the Mullard Resear Laboratories for permission to publish this paper.

REFERENCES

(1) Stoner, E. C. *Rep. Progr. Phys.*, **13**, p. 83 (1950).
(2) Webster, W. L. *Proc. Roy. Soc.*, **107**, p. 496 (1925).
(3) Bozorth, R. M. *Ferromagnetism*, p. 579 (New Yor D. Van Nostrand Co. Inc., 1951).

A servo-mechanism for the study of self-extinction of gaseous discharges in cavities in dielectrics

By E. C. Rogers, B.Sc., Grad.I.E.E., Grad.Inst.P., E. B. Page, B.Sc., and V. G. Harriss, British Insulated Callender's Cables Ltd., London, W.12

[*Paper received* 3 *August*, 1955]

A servo-mechanism is described which automatically measures and records the extinction voltage of discharges that occur in gas-filled cavities in dielectric samples subjected to 50 c/s alternating stresses. The discharges are detected by an electronic system, which operates an electromechanical unit controlling the testing voltage applied to the sample. This testing voltage is normally set at about four to five times the initial discharge inception value. At regular intervals, the servo-mechanism reduces the testing voltage until extinction of discharges occurs, and then returns it to the previous value. A continuous record of the testing voltage presents the variation of discharge extinction voltage with time in an easily assimilated form, thus providing a convenient method of studying self-extinction phenomena. An example is given of an extinction voltage/time curve plotted by the machine for a polyvinyl chloride sample containing an artificial cavity.

e study of gaseous discharges in cavities in dielectrics jected to power frequency stresses is of considerable erest to the cable and capacitor manufacturer, and any thod of inhibiting such discharges would be of great value. has been shown that, over the range in which Paschen's v is applicable, the initial breakdown stress of a gas is lependent of whether the bounding surfaces are of metal dielectric.(1) If, however, a dielectric containing a gas-ed cavity is subjected to a 50 c/s alternating stress slightly her than the initial discharge inception value, the discharges frequently observed to cease after a few minutes. By sing the applied stress the new inception value may be nd, and the discharge re-established. Hence spontaneous pression of discharges can occur, and the phenomenon is med "self-extinction." The phenomenon is conveniently died by applying a constant a.c. stress to a cavity-containing nple, of about four to five times the initial discharge eption value, and measuring the extinction voltage at ular intervals, e.g. 5 min. Values of discharge extinction ltage can then be plotted against time, giving the "self-tinction characteristic" of the sample. The servo-chanism described below was developed for the purpose carrying out these measurements automatically. Before scribing the servo-mechanism, a brief outline will be given the method of detecting internal discharges in dielectric mples, and their characteristics.

THE DETECTION OF DISCHARGES

The construction of the test sample, and the electrode stem used, are shown in Fig. 1. Tests have so far been nfined to polyvinyl chloride samples containing artificial lindrical cavities. These samples are made up from three lyvinyl chloride disks, each of 0·013 in. nominal thickness d 2 in. diameter, pressed together and sealed at their edges th an oil-resistant adhesive. The cavity is made by cleanly nching the middle disk at its centre with a $\frac{1}{16}$ in. diameter le. Prior to assembly, a $\frac{9}{16}$ in. diameter silver electrode is posited centrally on the outside surface of each of the ter disks by evaporation in a vacuum. These silver ctrodes ensure intimate electrode-dielectric contact, and lp to eliminate spurious discharges.

For testing, the sample is held centrally between $\frac{3}{4}$ in. ameter brass electrodes, which make contact with the silver ctrodes on the sample. The whole assembly is immersed a high viscosity mineral oil to suppress external discharges.

The upper brass electrode is connected to the high voltage end of the secondary of a 10 kV discharge-free testing transformer, and the lower electrode is returned to the earthed end of the secondary through a 100 kΩ series resistor *R*. Discharges in the sample cause current pulses to flow in the circuit, and the resulting voltage pulses developed across the resistor may be amplified and displayed on an oscilloscope. The 50 c/s voltage component which also appears across the resistor is rejected by a simple high-pass filter.

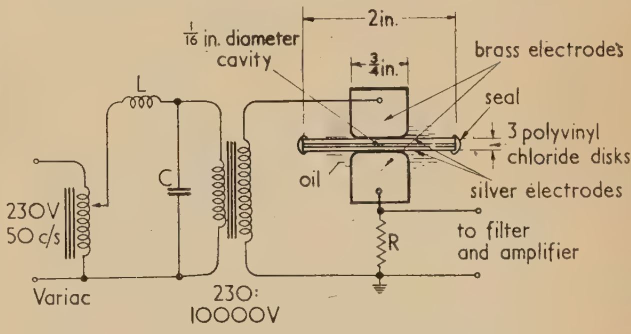


Fig. 1. Sample construction and electrode system

The testing transformer primary is fed from a Variac. High-frequency mains interference is rejected by a low-pass filter, made up of the air-cored choke *L* and the discharge-free capacitor *C*.

CHARACTERISTICS OF THE DISCHARGES

Suppose an alternating voltage is applied to the brass electrodes of Fig. 1, of peak value such that the breakdown stress of the air in the cavity is just exceeded. If it is assumed that the opposite plane faces of the cavity discharge uniformly, the discharge sequence will take the idealized form described by Whitehead.(2) In the absence of discharges, the voltage waveform developed across the cavity would be sinusoidal as shown by the dotted curve of Fig. 2(*a*). However, the discharge inception voltage V_i is exceeded just before the first voltage peak, and the resulting discharge reduces the voltage across the cavity to a small residual value V_r, in a time not more than 0·1 μs. The voltage across the cavity is then the algebraic sum of the voltage due to the applied field and that due to the separated charges. A discharge occurs each time the voltage across the cavity attains the inception value V_i, and for an applied voltage of peak value just in excess of V_i, two discharges would be expected per half-cycle, as shown by the full line of Fig. 2(*a*). After rejection of the 50 c/s component, the output waveform developed across the resistor R_1, Fig. 1, would consist of a series of sharp pulses, each pulse corresponding to a discharge, as shown in Fig. 2(*b*).

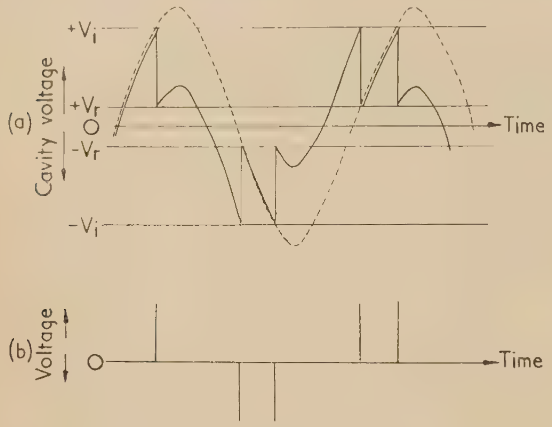


Fig. 2. (*a*) Idealized voltage waveform across a discharging cavity

- - - - - = waveform of applied voltage.
——— = waveform of voltage across cavity.

(*b*) Output waveform, after filtering

In practice, the cavity faces do not discharge uniformly, and the sequence of discharges is more complex.(3) It is sufficient to note, however, that the discharge pulses increase in number per half-cycle as the applied voltage is raised, but remain of more or less constant amplitude. The onset of discharges as the applied voltage is slowly raised through the inception value is usually an intermittent process, rather than a sharp cut-on, and the same is true of the cessation of discharges, as the voltage is lowered through the extinction value.

For a cavity-containing sample of the dimensions quoted, the duration of the voltage pulses across resistor R_1 would be of the order of 1 μs, and the pulse amplitude approximately 0·1 V.

THE SERVO-MECHANISM

A 50 c/s testing voltage V_t of about four to five times the initial discharge inception voltage is normally applied to the sample, so that initially, at least, multiple discharges occur in the cavity during each half-cycle. At 5 min intervals the applied voltage is automatically lowered until extinction of discharges occurs, and then immediately returned to the testing value again. The testing transformer primary voltage is continuously recorded, so that values of the discharge extinction voltage are plotted as the extremities of a series of downward going spikes on the recorder chart. For this purpose the extinction voltage V_e is taken as the voltage at the time when pulses have been absent for a period of t seconds. The delay period t is normally set to about $\frac{1}{2}$ s.

In order to minimize interference with the self-extinction process, it is desirable to carry out the measurement of V_e as rapidly as possible. However, to minimize overshoot due to the inertia of the system, a slow approach to V_e is also desirable. To meet these conflicting requirements the servo-mechanism operates at two speeds. The voltage is reduced from the testing value V_t at high speed, until disch become intermittent, indicating that extinction is immi The extinction voltage V_e is then approached at slow s and, on cessation of discharges, the voltage is returned t testing value V_t again, at high speed.

The circuit is conveniently considered in two parts:

(1) the electronic system, which detects the onset of i mittency, and the extinction of discharges as voltage across the sample is lowered, and
(2) the electro-mechanical system, which controls voltage in the prescribed manner.

The electronic system.—A circuit diagram of the syste shown in Fig. 3(*a*). The output waveform developed a R_1 is applied to a simple high-pass filter, which rejects 50 c/s component and passes the discharge pulses to input of a two-stage amplifier (V_1 and V_2) of the conventi *RC* coupled type. The amplified pulses, taken off potential divider R_{11}, which serves as a gain control, ar to a cathode follower buffer stage V_3. Provision is ma this point for an output to an oscilloscope for monit purposes.

The output of the buffer stage is employed to trigg single-shot multivibrator V_4, which has a relaxation slightly less than the period of the 50 c/s waveform. In presence of regular recurrent pulses, of at least one per cycle, the multivibrator is triggered in every cycle by negative-going pulses on the grid of V_{4a}. The triode is then conducting during most of each cycle, and the m anode current is sufficient to operate the *C* relay. When *C* relay operates, contacts *C*2 close, connecting R_{17} in s with the relay coil. This drops the current in the *C* r coil to just above the hold value. When the discha become intermittent, the multivibrator is no longer trigg in every cycle, and the fall in the mean anode current of causes the *C* relay to break. Contact *C*1 makes before breaks, and so the onset of intermittency is indicated by momentary closing of *C*1.

The rectified output of V_{4b}, consisting of negative pulse applied to the delay circuit. A single pulse is sufficien charge capacitor C_{19} to a negative voltage large enough bias the anode current of V_7 to below the hold value of *D* relay. In the absence of further pulses, the charge le away at a rate determined by the setting of the delay con R_{23}, and the grid voltage of V_7 rises exponentially. anode current of V_7 also rises, and after pulses have b absent for a period of *t* seconds, the *D* relay operates. He the occurrence of extinction, i.e. the absence of pulses *t* seconds, is indicated by the closing of the *D* relay.

A negative going pulse of amplitude 2 V is sufficient trigger the multivibrator, and this determines the sensiti of the system. The overall amplifier gain is about 300, that the discharge pulses developed across R_1 must be grea than 6·7 mV to be detected. The pulse amplitude fo sample of the dimensions quoted is of the order of 100 m so the sensitivity is more than adequate for this type sample.

The electro-mechanical system. A circuit diagram of system is shown in Fig. 3(*b*). Basically, the system cons of a motor-driven Variac supplying the input voltage to testing transformer, together with control circuits for motor. The Variac is driven through a 2500 : 1 step-do gear train by a fractional h.p. shunt-wound motor of the commutator type. The motor speed is adjusted, by mea of resistors R_{27} and R_{28}, so that the Variac shaft is norma ned at a speed of 1 rev/min, corresponding to a change of r.m.s./s on the testing transformer primary, i.e. 200 V .s./s on the sample. At the onset of intermittency, tacts $B2$ open, resistor R_{26} is switched into series with the rmature windings and the Variac shaft speed falls to rev/min.

Limit switches X_2 and X_3 are operated by cams on the ariac shaft, and can be adjusted to operate at any Variac ttings. X_3 is set to break when the testing voltage V_t is ached, and X_2 breaks only when the Variac is turned down zero voltage.

The micro-switch X_1 is closed for periods of $2\frac{1}{2}$ min, at tervals of 5 min, by a rotating sector driven by a synchronous motor. The closing of this switch causes the servo-mechanism to commence its operating cycle.

The relays A, B, C, D and E are standard Post Office types. As previously stated, relays C and D are operated by the electronic unit, and indicate the onset of intermittency, and the cessation of discharges respectively. Relay A switches the motor on and off, E controls the direction of running and B controls the speed. Relay contact sets are denoted by $A1$, $A2$, . . .; $B1$, $B2$ . . . .

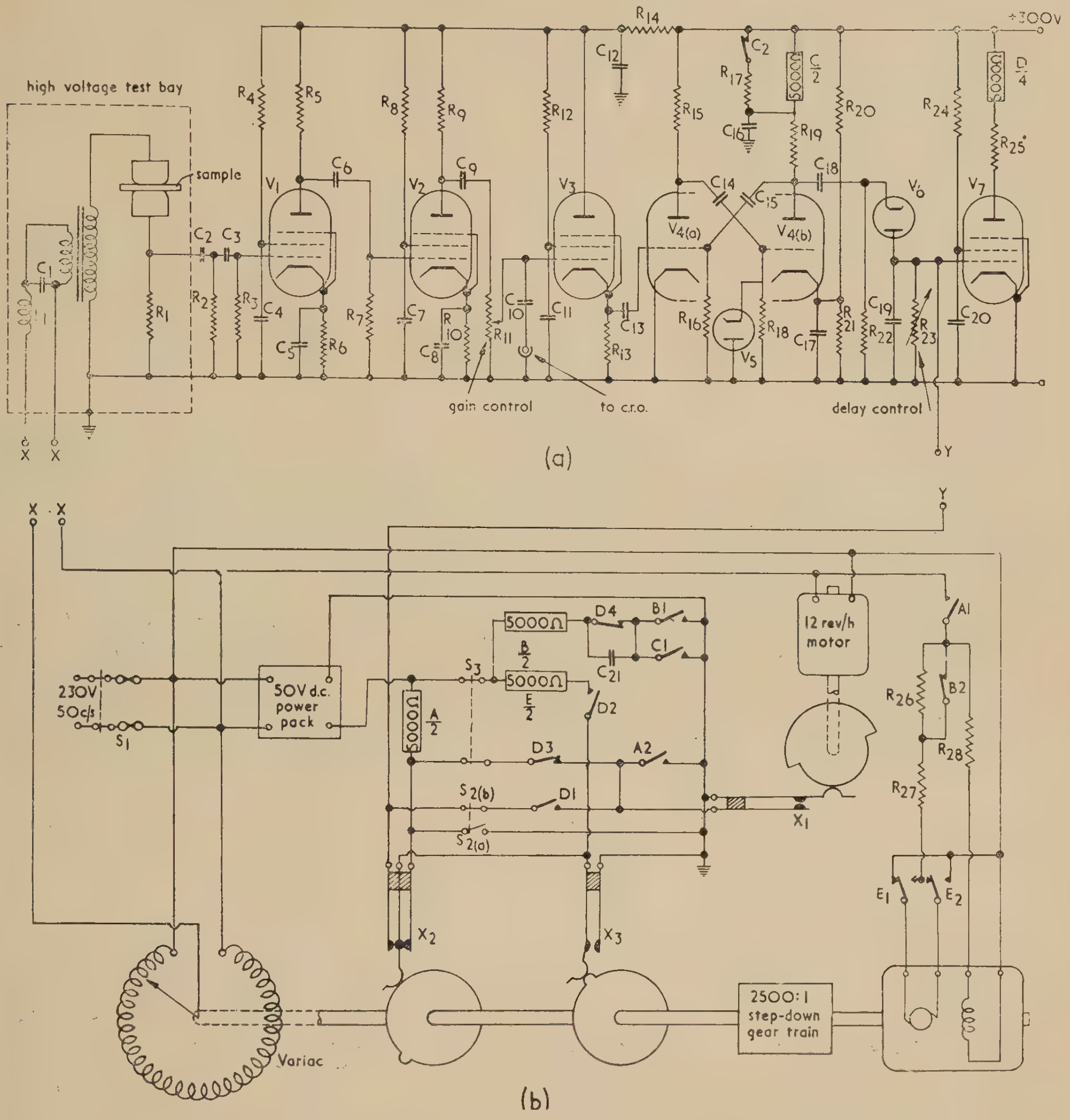

high voltage test bay
sample
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} R_{11} R_{12} R_{13} R_{14} R_{15} R_{16} R_{17} R_{18} R_{19} R_{20} R_{21} R_{22} R_{23} R_{24} R_{25}
C_1 C_2 C_3 C_4 C_5 C_6 C_7 C_8 C_9 C_{10} C_{11} C_{12} C_{13} C_{14} C_{15} C_{16} C_{17} C_{18} C_{19} C_{20}
V_1 V_2 V_3 $V_{4(a)}$ $V_{4(b)}$ V_5 V_6 V_7
C2
5000Ω
C/2
D/4
+300V
gain control
to c.r.o.
delay control
X X
Y
(a)
X X
Y
230V 50c/s
S_1
50V d.c. power pack
5000Ω
D4
B1
B/2
C1
S_3
5000Ω
C_{21}
E/2
D2
A/2
D3
A2
$S_{2(b)}$
D1
$S_{2(a)}$
12 rev/h motor
A1
R_{26}
B2
R_{28}
R_{27}
X_1
E_1
E_2
X_2
X_3
Variac
2500:1 step-down gear train
(b)

Fig. 3. (*a*) Circuit of electronic system. (*b*) Circuit of electro-mechanical system

$R_1 = 100\ \text{k}\Omega$
$R_2, R_3 = 470\ \text{k}\Omega$
$R_4 = 47\ \text{k}\Omega$
$R_5 = 24\ \text{k}\Omega$
$R_6 = 470\ \Omega$
$R_7 = 470\ \text{k}\Omega$
$R_8 = 47\ \text{k}\Omega$
$R_9 = 24\ \text{k}\Omega$
$R_{10} = 470\ \Omega$
$R_{11} = 470\ \text{k}\Omega$
$R_{12} = 47\ \text{k}\Omega$
$R_{13} = 24\ \text{k}\Omega$
$R_{14} = 10\ \text{k}\Omega$
$R_{15} = 47\ \text{k}\Omega$
$R_{16} = 330\ \text{k}\Omega$
$R_{17} = 3\cdot3\ \text{k}\Omega$
$R_{18} = 220\ \text{k}\Omega$
$R_{19} = 10\ \text{k}\Omega$
$R_{20} = 50\ \text{k}\Omega$
$R_{21} = 3\cdot3\ \text{k}\Omega$
$R_{22} = 100\ \text{k}\Omega$
$R_{23} = 1\ \text{M}\Omega$
$R_{24} = 47\ \text{k}\Omega$
$R_{25} = 41\ \text{k}\Omega$
$R_{26} = \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\}$ see text
$R_{27} =$
$R_{28} =$

$C_1 = 10\ \mu\text{F}$
$C_2 = 8\ \text{pF}$
$C_3 = 80\ \text{pF}$
$C_4, C_5 = 0\cdot1\ \mu\text{F}$
$C_6 = 80\ \text{pF}$
$C_7, C_8 = 0\cdot1\ \mu\text{F}$
$C_9 = 80\ \text{pF}$
$C_{10} = 0\cdot01\ \mu\text{F}$
$C_{11} = 0\cdot1\ \mu\text{F}$
$C_{12} = 16\ \mu\text{F}$
$C_{13} = 0\cdot01\ \mu\text{F}$
$C_{14}, C_{15} = 0\cdot1\ \mu\text{F}$
$C_{16} = 8\ \mu\text{F}$
$C_{17} = 32\ \mu\text{F}$
$C_{18}, C_{19} = 0\cdot5\ \mu\text{F}$
$C_{20}, C_{21} = 0\cdot1\ \mu\text{F}$

$V_1, V_2, V_3 = 6\text{F}13$
$V_4 = \text{ECC}33$
$V_5, V_6 = \text{EA}50$
$V_7 = 6\text{F}13$

THE OPERATING SEQUENCE

In Fig. 3 all switches and relay contacts are shown in position for the "testing period," when the voltage applied to the sample is V_t. Commencing from this period in the operating cycle, the switching sequence is as follows. When the timing switch X_1 closes, the A relay circuit is made, through S_3 and $D3$, and the A relay operates. The closing of $A1$ switches on the motor, and, as the E and B relays are not operated, the Variac is driven in the "reduce volts" direction at full speed. The upper limit switch X_3 makes as soon as the Variac shaft starts to move, so that the A relay circuit is now also made through a second path, i.e. through the limit switches X_2 and X_3.

When the discharge become intermittent, relay C breaks, and the momentary closing of $C1$ completes the B relay circuit. The B relay operates and is locked in the operate position by the closing of $B1$. The breaking of $B2$ changes the motor speed to slow.

When extinction occurs, the D relay operates. This relay carries four contact sets, which perform the following functions: (*a*) $D1$ closes, connecting the grid of V_7 to earth through X_1, thereby locking the D relay in the operate position; (*b*) $D2$ makes, and completes the E relay circuit. The E relay operates, and the change over of $E1$ and $E2$ reverses the motor; (*c*) $D4$ breaks, releasing the B relay, and closing $B2$. Hence the Variac is now driven in the "raise volts" direction at full speed; (*d*) $D3$ breaks, so that the A relay circuit is now only made through the limit switches X_2 and X_3.

The motor continues to run until the testing voltage is reached, when limit switch X_3 breaks and releases the A relay. The breaking of $A1$ then switches off the motor. The operating cycle is completed by the opening of X_1, which frees the grid of V_7. This enables the D relay to break, releasing relay E, and restoring the whole system to its initial state.

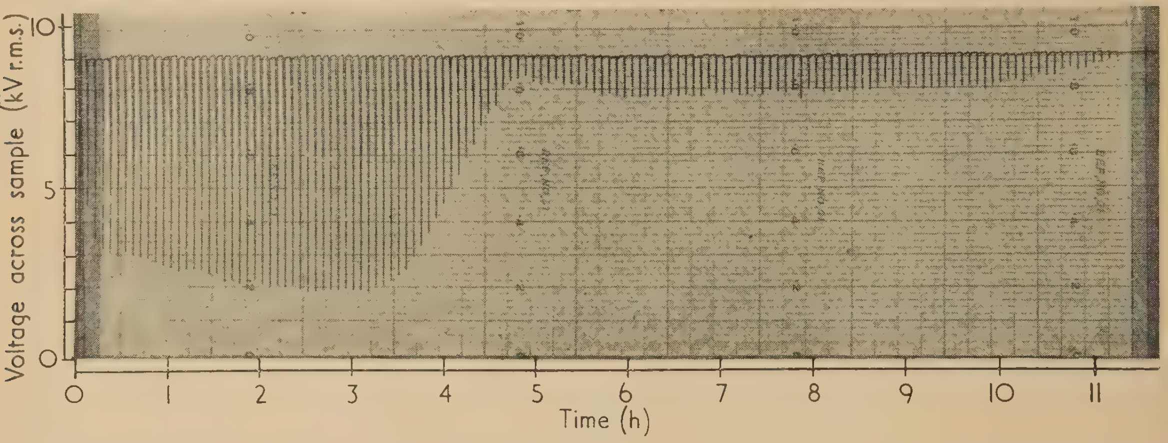


Fig. 4. Example of an automatically plotted self-extinction/time curve for discharges in a polyvinyl chloride samp

This cycle of operations occurs at 5 min intervals, determined by the timing switch X_1. The cycle may be initiated at other times, however, by operating the press-button switch S_2. The momentary closing of $S_2(a)$ completes the A relay circuit, which is now locked in the operate position by $A2$ instead of X_1. If X_1 happens to be closed when S_2 is pressed, the momentary breaking of $S_2(b)$ frees the grid of V_7, and relays D and E are released. Hence S_2 has overriding control, and an operating cycle may be triggered at any time, regardless of the position of the timing switch.

The system may be closed down by opening S_3, and pressing S_2. The A relay operates, and the Variac is driven in the "reduce volts" direction at full speed. Since S_3 is open, relays B and E cannot now operate when disch cease, and the Variac is driven down to the zero-volts po when the limit switch X_2 operates. The changeover c breaks the A relay circuit, stopping the motor, and also the D and E relays in the operate position by earthing grid of V_7. Hence the motor circuit is reversed in prepar for starting up again. To start it is only necessary to S_3 and press S_2. The Variac is then driven in the " volts" direction until the testing voltage is reached, an normal sequence of operation continues.

PERFORMANCE

A typical self-extinction characteristic recorded by machine is shown in Fig. 4. The test was made on a poly chloride sample of the type and dimensions already descri The initial value of extinction voltage V_e was 1·94 kV r. and the testing voltage was 8·9 kV r.m.s. Total extinctio the discharges occurred after 11 h, and no discharges detected in the remaining 12 h of the test. Monitorin the discharge pulses with an oscilloscope showed that operation of the servo-mechanism was entirely satisfactory, that prompt reversal took place on extinction of discharg

The machine has proved itself reliable in operation, has run without attention for tests of several days' durati By its use, prolonged observation may be made of behaviour of discharges in cavities in dielectrics that wo be exceedingly laborious and time-consuming, if not practicable, by the usual "manual" techniques. Moreov the results of the tests are presented in an immediat assimilable form, without the need for tedious graph-plotti

ACKNOWLEDGEMENTS

Acknowledgements are due to Dr. L. G. Brazier, Direc of Research and Education, British Insulated Callend Cables Ltd., for permission to publish this paper, and Mr. H. C. Hall for interest and encouragement during course of the work.

REFERENCES

(1) HALL, H. C., and RUSSEK, R. M. *Proc. Inst. Ele Engrs*, **101**, (II), p. 47 (1954).

(2) WHITEHEAD, S. *Dielectric Breakdown of Solids*, 2nd e p. 171 (London: Oxford University Press, 1953).

(3) MASON, J. H. *Proc. Inst. Elect. Engrs*, **100** (IIA), p. 1 (1953).

Some parasitic deflexions in parallel spring movements

By Prof. R. V. Jones, C.B., C.B.E., D.Phil., F.R.S.E., F.Inst.P., and I. R. Young, B.Sc., Grad.Inst.P.,
Natural Philosophy Department, University of Aberdeen

[*Paper received* 10 *October*, 1955]

This paper analyses some parasitic departures from parallel and rectilinear movement in simple and compound assemblies. The following factors are considered: accuracy of construction, geometrical proportions, spring variations, spring distortion, platform bending, clamp distortion, and gravity effects. It is shown that the "ideal" height at which to drive a parallel spring element is at half the spring height, and it is concluded that while spring tolerances are surprisingly "easy," care must be taken with the platforms and clamps if the highest performances are to be achieved.

In compound movements, the possibility of "slaving" the intermediate platform, suggested by Plainevaux, has been tested in practice with good results.

arallel spring movements are designed to produce parallel rectilinear displacement of a platform.(1) Such movements ave many applications in instrument construction, but there e factors to which attention must be paid if a specified erformance is to be attained. This paper therefore evaluates ome factors which affect the accuracy of performance of arallel spring movements; it also indicates how errors can e minimized.

The factors which the authors have found to be of some nportance in causing parasitic deflexions are:

(1) inaccurate construction;
(2) unfavourable geometrical proportions;
(3) variations in spring material;
(4) bending of the springs into other than the intended S-form;
(5) bending of the platforms holding the springs;
(6) distortion of the clamping pieces;
(7) forces such as gravity acting on the platforms in addition to the spring forces.

hese factors will be considered in turn, but first it is desirable o consider the elementary theory of an ideal parallel spring ystem.

THEORY

Consider a simple parallel spring movement, as in Fig. 1(*a*). he moving platform is assumed weightless, and the two prings are identical. The platform is deflected by a force F

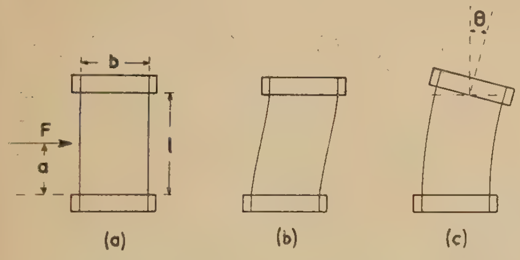


Fig. 1. Simple parallel movement: (*a*) undeflected, (*b*) intended parallel deflexion, (*c*) undesired cantilever bending

cting parallel to the base; the point of application of F either on the platform itself or on a rigid extension to e platform (not shown). The consequent position of the oving platform can be approximately described by the superposition of two deflexions, the intended one [Fig. 1(*b*)] due to equal S-bending of both springs, and an undesired one [Fig. 1(*c*)] which is the result of the system tending to bend as a cantilever. The latter will produce a deviation from purely parallel motion which will vary in magnitude with the height of the line of action of F; one can see intuitively that the deviation will change sign when this height is reduced sufficiently.

For small displacements the "pitching angle" θ of the moving platform when it is displaced a distance x is given by

$$\theta = \left[\frac{6(l-2a)t^2}{3b^2l - 2t^2l + 6at^2}\right]\left(\frac{x}{l}\right) \qquad (1)$$

where l = free length of springs (strictly, the perpendicular distance between the blocks).
t = thickness of springs,
b = length of platforms between springs,
a = height of line of action of F above fixed end of springs.

Since in practice t is much smaller than the other quantities, this may be written

$$\theta = \left[\frac{2(l-2a)t^2}{b^2l^2}\right](x) \qquad (2)$$

This formula is a useful guide to the performance of an ideal parallel spring system, since it shows the inherent deviation from parallel motion which may be expected, entirely in terms of the geometry of the system.

The application of the formula is limited by the original assumption that the platforms are weightless, but it gives results close to those found experimentally in cases where the platforms have sizes and weights typical of those used in practice, and where they are carrying components such as spectroscopic slit jaws and eyepieces. Formulae corresponding to equation (2) can be developed where heavy weights are being carried, but they will differ with the weight distribution and with the attitude of the system relative to the direction of gravity. Each case is then best treated individually, but some qualitative considerations are given later.

SYSTEMS TESTED

In the investigations which led to the present paper, several parallel spring systems were tested. For the purposes of illustration, reference will be made to two of the movements. One was a simple movement, with dimensions as follows: free spring length 76 mm, platform length 76 mm, spring width 25·4 mm, length held under clamps at each end 25·4 mm. Spring thicknesses from 200 to 500 μ were used in various trials.

The other system was compound, of the type shown in Fig. 2. *A* was the fixed platform, and *K* the platform intended to move in a straight line. The assembly *DFHGE* formed the intermediate platform, and *RU* and *ST* the spring pairs. *B*, *C*, *M*, *N* were clamping pieces holding the springs to the appropriate blocks. The free length of the springs was 100 mm, and the width 25 mm; the length held under clamps was 25 mm at each end. The length of *K* and *H* was 100 mm, and the other blocks were of minimum lengths compatible with their functions. The maximum movement of *K* was 20 mm. All blocks and clamps were of 25 mm × 25 mm cross-section and were held together where necessary by four 4 B.A. bolts. This movement could be used for investigating the behaviour both of a compound system, and of the simple system formed by *A*, the assembly *DFHGE*, and the spring pair *RU*. The springs were of half-hard beryllium copper, 500 μ thick, and the blocks were of Duralumin. The drive could be applied either to the intermediate or to the final platform, and the height of drive could be varied from the bottom to the top of the springs.

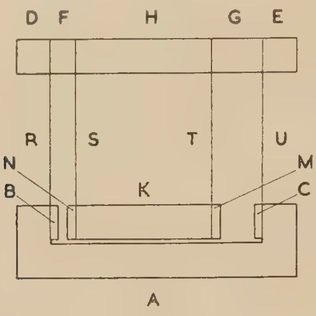


Fig. 2. Compound movement for tests of rectilinearity

PROPORTIONS

Formula (2) provides some guidance on proportions, but it needs to be considered against the background of the specific requirements of a particular application. The deviation from parallelism, for example, is dependent on t^2, and it is therefore desirable on this account to use as thin springs as possible. This, however, entails weakening the springs, which may be unfeasible if they have to carry a load. Thinness can be partly offset by widening the springs, but the spring strength is proportional to the cube of the thickness and to only the first power of the width. Moreover, the spring material is rarely perfectly flat, and the wider the strip the greater the risk of some departure from flatness.

Similarly, the formula indicates the value of making *b* as large as possible, but this implies long platforms which will be both heavier and less rigid than short ones. Both weight and rigidity are factors which, as will be seen later, affect departures from ideal motion, and thus set limits to the permissible lengths of the platforms.

ACCURACY OF CONSTRUCTION

The design should obviously be such as to facilitate accurate construction. Platforms and clamps should be milled or ground to their intended sizes. Whenever blocks occu pairs, as do *H* and *K* in Fig. 2, it is convenient to mac them together to ensure identity of dimensions. Units s as *HSKT* should be as accurate parallelograms as possi This is most easily done by making a rectangular block correct dimensions to use as a jig around which *HSKT* be assembled. Care has similarly to be taken in more com cated assemblies such as *A*, *R*, *FGH*, *U*; in this partic design two additional jig blocks were made, of the s height as the jig for *HSKT*, so that one could be inse between *D* and *A*, and the other between *E* and *A*. Th ensured that *R*, *S*, *T*, *U*, were as nearly equal in length possible. By such devices an assembly can be made w adequate geometrical accuracy, and attention should alw be paid to this point in the original design. It was the rea in the design described, for example, for the large size of blocks *D* and *E*, which otherwise could have been sim clamping pieces like *B* and *C*.

Clamping pieces should obviously be fitted properly their platforms. In particular, for example, the up surfaces of *B* and *C* should lie in the same plane as the up surface of *A*. This could be effected sufficiently accura by eye, although dowelling of both clamps and springs to platforms would have been more positive.

Tests were made on the simple parallel spring movem of the relative importance of errors in block and spr lengths. It turned out that there was a considerable differen The blocks and springs were about equal in length, be roughly 76 mm each. When one block was made lon than the other by ±0·25 mm, the effect was to cause moving block to pitch by about ±90″ for a lateral trave 10 mm, whereas when one spring was made longer than other by the same amount, the pitching was only ±7″ the same travel. Despite the large difference between two cases, these figures are consistent with formulae wh may be obtained by considering the parallel spring elem as a quadrilateral of rigid links hinged together at th extremities. If [Fig. 3(*a*)] the blocks are of equal lengt

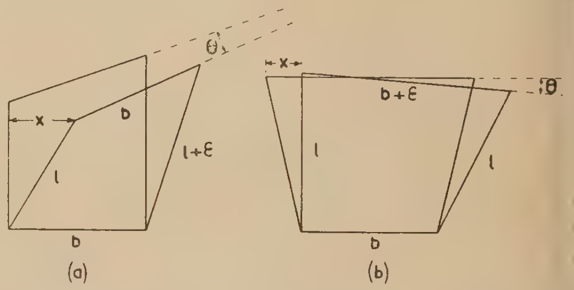


Fig. 3. Deflexion from parallelism of motion for a simple movement: (*a*) when block lengths *b* are equal and spring lengths differ by ϵ, (*b*) when spring lengths are equal and blocks lengths differ by ϵ

while one spring length is *l* and the other $(l + \epsilon)$ where is small, then the change in inclination of the moving blo for a sideways displacement *x* from the position correspond to spring equilibrium is approximately given by

$$\theta = \epsilon x^2/2l^2b \qquad ($$

In the other case [Fig. 3(*b*)] where the springs are of eq length *l* and the blocks unequal by an amount ϵ, the corr sponding expression is

$$\theta = \epsilon x/lb \qquad ($$

ese expressions give $\theta = 5{\cdot}9''$ and 89″ respectively, reeing well with the measurements. The extreme insen- ivity to inequalities in spring lengths means that tolerances n be "easy" here; this is fortunate, since the spring lengths the most difficult feature of the system to set to accurate lues.

If parallel motion to 1″ over 10 mm displacement is sired, then the block lengths have to be identical to within or 3 μ, and the spring lengths to within about 30 μ—ughly "one-tenth thou" and "one-thou" tolerances respec- ely—for block and spring lengths of the order of a few ntimetres.

Obviously, the possible trials in geometrical variations, ch as, for example, the non-parallelism of block faces, uld be extended indefinitely; from various trials along these ies, the authors find that they lead to conclusions regarding lerances of the same order as those just given.

VARIATIONS IN SPRINGS

The performance of the simple system was also tested with rings of intentionally different widths in order to simulate rors in cutting the strips, and variations in their thickness. ne spring was maintained at 25 mm width, while the other as successively made of 22 mm and 19 mm width, and then placed by one which tapered from 25 mm width at one end 19 mm width at the other. The deviation from parallel avel over a distance of 10 mm was in the worst case 9 mm width) 12″; the 22 mm width and the tapered strip oduced about 6″. These effects were surprisingly small, id yet were more than could be expected from variations spring thickness and width when reasonable care is being ken to produce as identical springs as possible. The above sts were made with 500 μ thick strip, for which the akers' (Johnson, Matthey and Co. Ltd.) standard tolerance ±25 μ.

The above conclusion was confirmed by repeated inter- anges of the springs in the design shown in Fig. 2. These terchanges did not produce more than a maximum difference the deflexion of K over 20 mm travel of more than 5″. his error was smaller than others considered later, and it is erefore concluded that, providing simple precautions are ken, such as cutting the springs from the same sheet f material, variations in spring dimensions are unlikely be important in producing errors in parallel-spring stems.

The heat treatments of all the springs in any one system ould obviously be identical.

CANTILEVER BENDING

Formula (2) shows that for small displacements, the devia- on from parallel motion can be made zero by driving the stem at a height midway between fixed and moving plat- rms. This conclusion has been extended to appreciable isplacements by Dr. C. W. McCombie, using a symmetry gument. The authors have confirmed it by experiment, though the effect of changing the height of drive is not ery great, and it is apt to be masked by other effects discussed ter.

In the design of Fig. 2, for example, when the deflecting rce acted in the line of the top of the springs it produced extra 6″ of deviation of the top platform when travelling mm from that which occurred with the drive at the mid-height of the springs. For the compound movement, travelling 20 mm, the corresponding deviation was 12″. Thus a total difference of 24″ could be produced in the compound movement by changing the line of action of the driving force from the top of the bottom of the springs. When the masking effects due to other causes were eliminated, it became clear that the mid-height was the ideally correct height at which to drive a simple or a compound spring system. This conclusion was further confirmed on the other simple system to which reference has been made, and the magnitude of the effect of varying the driving height was confirmed quantitatively.

It should be noted, however, that this effect is often not large compared with some of the effects due to other causes mentioned in this paper and, depending on the magnitude of these effects, it may sometimes be better to drive the movement at other than the ideally correct height.

SIDEWAYS DEVIATIONS

This paper is mainly concerned with deviations occurring in the plane bisecting blocks and spring longitudinally, since such deviations are to some extent inherent in parallel spring movements, and care must be taken to minimize them. If these deviations are described as "pitching" in the direction of motion, deviations can also occur in roll and yaw. These deviations are not, however, inherent. A yaw can arise, for example, if the force F (Fig. 2) acts to one side or other of the plane bisecting blocks and springs longitudinally, since it then exerts a torque tending to twist the moving platform about the base. In a simple parallel spring movement, for example, using springs of 80 mm free length, 20 mm width, and 50 μ thickness, displacing the line of the driving force sideways by 12 mm caused the movement to yaw by nearly 60″ in 10 mm travel. In order to reduce this to 1″, the driving force therefore must act within about $0{\cdot}2$ mm of the plane of symmetry.

Other sideways deviations may be produced by non-parallelism of the block faces, where tolerances have already been indicated, and by sideways thrusts or torques developed at the driving point. These can be much reduced by the use of a wobble-pin, as pointed out in a previous paper.(2)

BENDING OF THE PLATFORMS

In the trial movement of Fig. 2, the platforms were made of blocks of Duralumin of 25 mm × 25 mm cross-section, because it was thought that these would provide ample rigidity to enable all deviations found in the motion to be attributed to errors in the springs. It soon became clear,

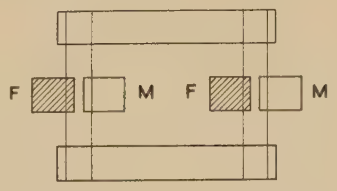


Fig. 4. A compensated movement with a high degree of symmetry. Blocks FF are fixed, and blocks MM (joined mechanically by a bridge outside plane of diagram) execute rectilinear motion

however, that the bending of the platforms was not only appreciable, but of such a magnitude as to produce comparable deviations with those caused in the springs, for example, by driving the movement at the incorrect height. There was an angle of 14″ between the end faces of *D* and *E*, assuming that these were initially parallel, after *K* had been displaced 20 mm. The fixed block *A* could easily be strengthened, but this could only be done for the top assembly by a considerable increase in weight.

The fact that platform bending is important had been noted in a previous paper.(2) In this respect, the first compound movement described in that paper is not as good, for example, as the compound movement described by Clay(3) in 1937. The third compound movement (Fig. 4 of Ref. 2), however, is most insensitive to platform bending, because of the high symmetry. Other arrangements, such as that shown in Fig. 4 of this paper may be even better.

In cases of doubt about the nature of the platform distortion, it might be worth making model movements with the platforms made of rubber or some other flexible material to show where maximum bending is likely to occur.

DISTORTION OF CLAMPING PIECES AND SCREWS

Clamping pieces in spring movements can sometimes be under considerable strain. The clamp *B*, for example, in Fig. 2 was originally of Duralumin 25 × 25 × 4 mm in dimensions, and held to *A* by four 4 B.A. brass screws. The effect of applying the force *F* was to make *R* tend to prise *B* away from the appropriate face of *A*; in practice this resulted in the screws holding *B* to *A* stretching sufficiently to change the orientation of *B*, and hence of the lower end of *R*, by 8″ when *F* was at its maximum value. This caused *K* to pitch by 4″ at its extreme position. The effect was much reduced by making *B* and its holding screws of mild steel.

The investigation thus shows that in some positions the clamps and their holding screws must be made unexpectedly strong. None of the other clamps in the design of Fig. 2 gave trouble comparable to that experienced with *B*.

GRAVITY FORCES

While rigidity is a primary requirement in the platforms, it can only be achieved at some expense in weight and volume. The platform material should obviously have the highest possible ratio of Young's modulus to density: on this account steel and Duralumin are among the best materials, but steel is generally preferable since it retains its dimensions more accurately.

The effect of weight on a simple parallel movement is to cause deviations from parallelism by varying the proportion of the weight carried by the two springs as they are deflected. Some advantage may be gained in this case by making the platforms long, since the distribution of weight will then change less for a given linear displacement of the moving platform. The magnitude of this trouble is, however, usually small.

Weight can have a much worse effect on a compound movement: parallelism is not seriously disturbed, but rectilinearity can be ruined. If, for example, an assembly such as that shown in Fig. 2 is operated in a vertical plane, the weight forces produce deviations from the rectilinear motion which *K* is designed to execute. They do this by tending to compress the springs *R* and *U* along their lengths, and to stretch *S* and *T*. The intermediate platform *H* inciden then moves further than its intended distance. The e increases with the horizontal displacement of *K*, wh therefore drops more and more from its intended horizo line of travel. In one movement investigated(4) the c amounted to 120 μ when the moving platform was displa by 20 mm; it was reduced to 70 μ by the discrimina removal of material from the platforms. The design of s a movement is then a compromise between lightness, givi more rectilinear motion but more angular deflexion due platform bending, and rigidity, giving less angular deflex but more deviation from rectilinearity. It is often poss to reach a useful compromise.

It is also possible to eliminate the foregoing defect aln completely by changing the spring direction relative to t of gravity. If, for example, the assembly shown in Fig is operated lying on its side, gravity then tends to twist t springs, rather than to stretch or compress them, and effect here is much less. The deviation of 70 μ for movement mentioned above was reduced to less than 1 by this procedure. If rectilinearity is important, therefo parallel spring movements should be operated whene possible with the free edges of the springs horizontal a the spring planes vertical. Further methods of achiev rectilinearity are described below.

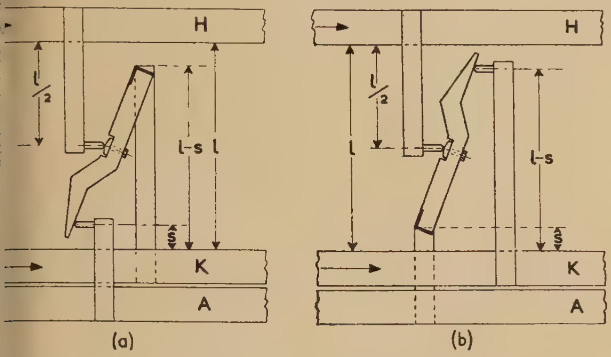
On more complicated movements, gravity may prod other undesirable deflexions; these may be minimized attending to the detail of the design. As an example, refere may be made to an optical slit designed by one of the pres authors,(5) where the jaws were carried on spring movemen and the width and parallelism of the slit had to be independ of its orientation relative to the direction of gravity. general, an arrangement can usually be found which mak the parasitic deflexion due to gravity small in at least c dimension, and this is frequently sufficient.

"SLAVED" COMPENSATION

The parasitic deflexion due to gravitational forces in compound movement has recently been considered theo tically by Plainevaux,(6, 7) who has suggested eliminating t deviation from rectilinear motion by altering the relati strengths of the springs, and by driving the intermediate pl form by a reduction gear (2 : 1 in the simplest instance) fro the same micrometer that drives the final platform. the expense of some complication, this could maintain t intermediate platform in the correct position to make t final platform move in a straight line almost independent the load.

The practical possibility of Plainevaux's proposal has be investigated by one of the present authors (R.V.J.). T proposed gearing has been replaced by a simple lev [Fig. 5(*a*) and (*b*)]; alternative arrangements are shown, a others may be possible. That shown in Fig. 5(*a*) has be investigated experimentally, and applied to the compou assembly of Fig. 2. The lever is pivoted on an angle-spri hinge(8) carried on the final platform *K*. The lever is o ginally vertical, with two pins bearing against it as show As *K* moves to the right the lever is rotated clockwise, sin it bears against the lower pin attached to the fixed block The upper pin, which bears approximately on the middle the lever, is carried by the intermediate platform *H*. T latter can now move to the right only as far as the lever w allow it, which is a distance one half of that moved by t final platform. The intermediate platform is thus constrain s correct position for the movement of the final platform e strictly rectilinear.

. slight complication in the lever design is caused by the that the path of any point in the intermediate platform f is not a straight line but a circle of radius equal to the ng length, so that the point of the pin moves in a circle he same radius. This causes the pin to drop slightly as platforms are moved; if the bearing surface on the lever e straight, the pin would therefore not be allowed to ve quite far enough to the right. This defect can be rcome by making the bearing surface on the lever part a semicubical parabola. The equation of this error is erent in the two cases shown: for Fig. 5(*a*) it should be



ig. 5. "Slaving" of intermediate platform applied to ompensated movement of Fig. 2: (*a*) lever hinged at nd nearer intermediate block *H*, (*b*) lever hinged at end nearer final block *K* and fixed block *A*

$$y = \sqrt{[8l(l-2s)/(3l-2s)^3]}\,x^{3/2} \qquad (5)$$

l for Fig. 5(*b*)

$$y = \sqrt{[8l(l-2s)/(l+2s)^3]}\,x^{3/2} \qquad (6)$$

ere l is the free spring length and s the distance of the hinge l the lower pin from their nearest platforms in the undected position. The surface can be conveniently generated a steel boss using a template made by reduction from a id-drawn curve in an engraving machine.

The effect of introducing the lever to "slave" the interdiate platform was impressive. Before its introduction, final platform of Fig. 2 dropped about 500 μ in 20 mm verse, under the weight of the platforms alone (0·5 kg). ter the lever and pins had been adjusted, the mean deviation m a straight line was about 0·1 μ in 20 mm traverse, der the weight of the platforms. An extra load of 3 kg ised a departure of not more than 2 μ at any point from line of traverse under no load. The "slaving" of the ermediate platform therefore makes the performance of movement comparatively free from the effect of loading.

The lever system was developed to test the possibilities of ving. It is open to some objection in that the sliding of the s on the lever introduces friction, but this defect is a minor , since comparatively small forces are involved. The lever may therefore be worth direct incorporation in parallel movements carrying appreciable loads, since it is simpler than a gear train.

CORRECTOR CLAMPS

One of the present authors(2) described a quick method of correcting undesired deflexions by suitably placed clamps on the springs. This method has been used satisfactorily in many applications, since it is often possible to neutralize the errors over a limited range of travel without having to trace their causes.

CONCLUSION

The object of the present paper has been to analyse the causes of parasitic deflexions, so that as many faults as possible can be minimized at the design stage. This may be helpful in facilitating the multiple production of spring movements. The performances given in this paper indicate how much can be done without empirical correction, and show the possibilities of "slaving" in compensated movements; the best figures achieved were a mean deviation from rectilinearity of 0·1 μ and from parallelism of 2″ over 20 mm movement. These performances may be compared with those given in a previous paper,(2) which were obtained (more easily) by the empirical use of corrector clamps.

The factors enumerated in this paper are not entirely independent, and design must compromise between them. The long blocks and thin springs indicated by elementary theory are not necessarily the best in practice, where the actions of internal and external forces may make thicker springs and shorter blocks preferable. Perhaps the most important aspect is the generosity in the spring tolerances which is permissible without spoiling performance.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help they have received from discussions with Dr. C. Strachan, Dr. A. H. S. Holbourn and Dr. C. W. McCombie.

REFERENCES

(1) A convenient bibliography is given by GEARY, P. J., *Flexure Devices*, B.S.I.R.A. Research Report M.18 (1954).

(2) JONES, R. V. *J. Sci. Instrum.*, **28**, p. 38 (1951).

(3) CLAY, R. S. *J. Roy. Micr. Soc.*, **57**, p. 1 (1937).

(4) JONES, R. V. *J. Sci. Instrum.* To be published.

(5) JONES, R. V. *A large optical slit mechanism. J. Sci. Instrum.* To be published.

(6) PLAINEVAUX, J. E. *Nuovo Cimento*, **11**, p. 626 (1954).

(7) PLAINEVAUX, J. E. *Nuovo Cimento*, **12**, p. 37 (1954).

(8) JONES, R. V. *J. Sci. Instrum.*, **32**, p. 336 (1955).

The stability of thermistors

By A. Beck, B.Sc., A.Inst.P., Australian National University, Canberra, Australia

[*Paper received* 2 *September*, 1955]

Although thermistors may reach a state where their constants remain stable, they may later undergo a change which takes place in an arbitrary manner. It is still possible, within certain limits, to obtain relative temperatures accurate to within 0·02° C.

Thermistors are now widely used for the measurement of temperatures but very little information about their stability is available. Most authors who have used thermistors give the results of their experiments with practically no discussion of thermistor characteristics, while the little information which has been published shows that there is a wide divergence of opinion on their stability.

In measuring temperature differences of 0·01° C to an accuracy of 0·0002° C, Greenhill and Whitehead(1) avoided errors due to the variations in cold resistance by calibrating their instrument after each experiment. Doucet(2) gave the limit of accuracy of a bead-type thermistor as 0·002° C. After detailed investigations on a rod-type thermistor, Staley(3) found that, even after careful selection and calibration at least once a year, there was a maximum probable error of 0·4° C. Müller and Stolten(4) used a bead-type thermistor to undertake the thermometric determination of molecular weights and had to measure temperature differences of 0·001° C. The tables given in their paper indicate that the two thermistors used remained stable to better than 0·0001° C for periods up to thirty minutes and stable to 0·02° C for a period of six months.

The purpose of the present paper is to show that, although thermistors may be very unreliable for measuring absolute temperatures over long periods of time, they can, within certain limits, be relied upon to give relative temperatures to an accuracy of 0·02° C.

The author has been using thermistors for some years for measuring temperatures in boreholes for calculation of the geothermal gradient and heat flow. When in the laboratory, the thermistors are cycled at regular daily intervals over a range of temperatures greater than that which it is expected will be found in the field. All thermistors have been of the glass-enclosed, directly-heated bead-type and their resistances have been measured by an a.c. bridge.(5) It is known that the resistance R (Ω) is connected with the absolute temperature T by the relation

$$R = ae^{b/T}$$

where a and b are the "constants" of the thermistor. To determine the "constants," the resistance of the thermistor is measured at a series of known temperatures* at interv approximately 2° C. The mean of all the values of b obt from the calibration observations is used in conjunctior the resistance at the mean temperature to determine a of a. Using these constants, the temperatures are calculated from the observed resistances and compared the observed temperatures. As noted by other worker the "constants" are, in fact, functions of the tempera therefore, if the extreme error is greater than 0·01° calibration is divided into two ranges and the process repe The range over which one pair of "constants" can be us give temperatures to an accuracy of 0·01° C varies bet 6° and 12° C according to the thermistor used and the p of the R–T curve on which the range lies.

Because of doubts about their stability, the therm have, as far as possible, been calibrated in the labor both before and after a field measurement. This is possible on a prolonged field trip, and as it was found under field conditions a calibration could not be perfo to an accuracy of better than 0·1° C, the practice was add of using a centrally situated borehole for calibration pur These boreholes are filled with water and are of small di (2 in.) so the temperatures in them are very stable. I cases, temperatures are measured both on lowering raising the measuring head,(5) and the fact that these indicates that the thermistor has remained stable over period of the experiment.

As an example of such readings, the temperatures meas by two thermistors (1) and (2) in the same borehole on va dates are given in Table 1. For each date the values in first column, marked B, are calculated from constants d mined by laboratory calibration before leaving for the while those in the second column, marked A, are de from a calibration after returning to the laboratory months later. The values in the first column (24/2/54 agree with measurements made by maximum thermom and for this and other reasons are regarded as correct va

The fact that the values in the B and A columns are i

Table 1. *Temperature measurements in one borehole*

Depth (*ft*)	*Temperatures measured by thermistor No. 1 (° C)*										*Temperatures measured by thermistor No. 2 (° C)*				
	24/2/54		26/2/54		16/3/54		30/3/54		9/4/54		16/3/54		30/3/54		9/4/54
	B	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
200	10·83	12·99	10·81	12·97	8·82	10·96	8·75	10·89	9·09	11·22	10·85	11·53	10·83	11·51	10·84
300	11·40	13·57	11·38	13·54	9·40	11·54	9·32	11·47	9·65	11·80	11·42	12·10	11·40	12·08	11·42
400	11·99	14·17	11·97	14·15	9·98	12·13	9·90	12·06	10·23	12·39	12·01	12·69	11·99	12·67	12·01
500	12·61	14·79	12·58	14·76	10·59	12·75	10·52	12·68	10·86	13·02	12·62	13·31	12·61	13·29	12·63
600	13·21	15·39	13·19	15·37	11·18	13·34	11·12	13·28	11·45	13·62	13·22	13·91	13·21	13·89	13·23
700	13·83	16·03	13·80	15·99	11·79	13·96	11·73	13·90	12·07	14·24	13·84	14·52	13·82	14·51	13·84
800	—	—	14·40	16·60	12·38	14·56	12·33	14·51	12·65	14·84	14·44	15·13	14·43	15·11	14·45

---

* As equipment for platinum thermometry was not availab pair of "gold line" mercury in glass thermometers, recalibrate National Standards Laboratory at Sydney, has been used.

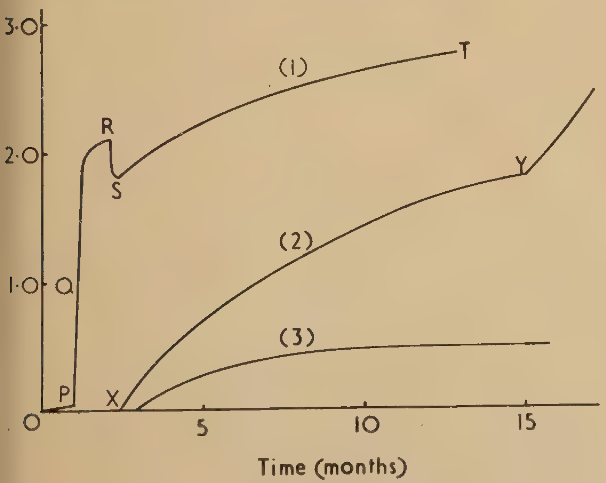
s very different indicates that both thermistors changed ' constants considerably during the two month period. vever, inspection of the values shows that this change has caused a simple displacement in the temperature/depth es so that the relative temperatures are still measured ectly (this is not quite true for No. 1 thermistor in which displacement in temperature is greater than 2° C). ilar results have been obtained in the laboratory and some iese are given in Table 2 which shows the results for No. 2 mistor derived from four laboratory calibrations made 1, 15 and 17 months after an original calibration at $\tau = 0$.

Table 2. *Results for No. 2 thermistor*

$\tau = 5$ *months*			$\tau = 11$ *months*			$\tau = 15$ *months*			$\tau = 17$ *months*		
t_0	t_c	$(t_0 - t_c)$	t_0	t_c	$(t_0 - t_c)$	t_0	t_c	$(t_0 - t_c)$	t_0	t_c	$(t_0 - t_c)$
5·27	4·60	0·67	14·09	12·59	1·54	14·22	12·42	1·80	11·71	9·29	2·42
6·60	5·93	0·67	16·62	15·07	1·55	16·16	14·35	1·81	13·95	11·52	2·43
7·88	7·21	0·67	18·46	16·91	1·55	18·44	16·62	1·82	16·18	13·74	2·44
9·32	8·64	0·68	20·46	18·90	1·56	20·55	18·73	1·82	18·50	16·05	2·45
10·73	10·05	0·68	22·38	20·82	1·56	22·44	20·62	1·82	20·76	18·30	2·46
12·02	11·34	0·68	24·28	22·72	1·56	24·63	22·81	1·82	23·05	20·58	2·47
13·29	12·61	0·68	30·89	29·32	1·57	26·68	24·85	1·83	25·37	22·89	2·48
14·59	13·90	0·69				28·68	26·85	1·83	27·63	25·14	2·49
15·87	15·18	0·69				30·84	29·00	1·84	29·90	27·40	2·50
17·21	16·52	0·69							32·24	29·73	2·51
18·31	17·62	0·69									

or each calibration the first column, marked t_0, gives the erved temperatures in ° C, the second column, marked t_c, es the temperatures calculated from the observed resistances ng the constants obtained from the calibration at time =0; the third column, marked $t_0 - t_c$, shows how the or in the calculated temperature increases as the tem-ature increases. It appears that over a range of approxi-tely 10° C, relative temperatures may be measured to an uracy of 0·02° C provided the change in constants is not great as to give an error greater than 1·5° C in the absolute nperature.

hese thermistors have been treated as carefully as possible ler rather difficult field conditions. No reason is assign-e for the change in constants of No. 2 which remained ble for more than two months before altering its charac-istics. It is probable that the change in constants of No. 1 was caused by its being left in direct sunlight for a short time on 24 February, 1954, when it was estimated to have reached a temperature 10° C higher than the maximum temperature to which it had previously been cycled.



Errors in temperature measured by various thermistors

The error based on the original calibration for each thermistor has been plotted against time in the figure. The thermal shock received by thermistor No. 1 took place at the point *P* on curve (1) and was followed by a rapid rise *PQR* in error; the readings *RS* were taken with the thermistor at constant temperature at 200 ft in the hole; the slow rise *ST* has continued since. The corresponding curve for thermistor No. 2 is shown in curve (2). The increase in error *XY* was comparatively uniform until a thermal shock, similar in magnitude to that received by thermistor No. 1, was applied at *Y*. The general tendency of the thermistors used has been to show a rise in resistance and so of error with time. Curve (3) shows the behaviour of a third thermistor which, so far as is known, has received neither thermal nor mechanical shocks.

CONCLUSIONS

Although thermistors may reach a state when their constants remain stable, it is possible for them to undergo a sudden change which takes place in a rather arbitrary manner. Adverse heat treatment is suggested as one possible cause and it appears that thermistors should not be subjected to temperatures outside the range of temperatures to be measured. The real cause probably lies deeper than this and until some method of manufacturing thermistors with completely stable characteristics is devised, it would be unwise to use two or more different thermistors to measure temperature difference in one experiment, unless a careful calibration of each thermistor was performed both before and after the experiment. However, if one thermistor only is used, provided the error in absolute temperature is less than 1·5° C, and provided the thermistor constants are stable over the period of measurement, relative temperatures may be relied upon to an accuracy of 0·02° C, over a range of 10° C. In general, the thermistor constants change slowly enough to enable them to be used, to this order of accuracy, in experiments of up to twenty-four hours duration, but for experiments longer than this, frequent checking of stability is advisable.

REFERENCES

(1) Greenhill, E. B., and Whitehead, J. R. *J. Sci. Instrum.*, **26**, p. 92 (1949).

(2) Doucet, Y. *J. Phys. Radium*, **12**, p. 823 (1951).

(3) Staley, R. C. *Amer. Met. Soc. Bull.*, **33**, p. 67 (1952).
(4) Müller, R. H., and Stolten, H. J. *Analyt. Chem.*, **25**, p. 1103 (1953).
(5) Newstead, G., and Beck, A. *Austral. J. Phys.*, **6**, p. 480 (1953).
(6) Becker, J. A., Green, C. B., and Pearson, G. L. *El Eng. Trans.*, **65**, p. 711 (1946).
(7) Bosson, G., Gutmann, F., and Simmons, L. M. *J. Ap Phys.*, **21**, p. 1267 (1950).
(8) Sillars, R. W. *J. Sci. Instrum.*, **19**, p. 81 (1942).

A mechanical binary-decimal converter

By M. Setterwall, M.Eng., The Research Institute of National Defence, Stockholm, Sweden

[*Paper received* 9 *June*, 1955]

A simple and reliable mechanical device is described which is able to convert a number N from binary to decimal form. Details are given of a ten-digit convertor, capable of exact conversion of numbers up to 1023. By using this in two steps, numbers up to $2^{20} \simeq 10^6$ can be converted with a relative accuracy better than $1/\sqrt{N}$.

The appearance in recent years of certain multi-channel kicksorters, delivering at a high rate large numbers of data presented in binary form, has made the problem of converting numbers from the binary to the decimal system a rather important one. This has led to the construction at this Institution of a simple mechanical conversion device.

REQUIREMENTS

The device is used to convert to decimal form the channel counts from a Hutchinson–Scarrot kicksorter.* This kicksorter displays the information (in binary form) on a cathode-ray tube screen as a series of bright and faint dots, corresponding to the digits 1 and 0 respectively.

The maximum channel storage capacity, equal for all channels, is $2^n - 1$ where n can be set at will from 10 up to 20. There is always inherent in the channel count a relative statistical error of the order $1/\sqrt{N}$, which means that the accuracy of conversion must at least be better than this. The fortunate existence of the approximation $2^{10} \simeq 10^3$ suggests the possibility to achieve this with a two-step method where a ten-digit converter is used twice. An n-digit $(20 \geqslant n > 10)$ binary number N, can be thought of as composed of two ten-digit numbers N_1 and N_2 where

$$N = \sum_{0}^{n-1} A_k . 2^k$$

$$N_1 = \sum_{n-10}^{n-1} A_k . 2^{k-n+10}$$

$$N_2 = 2^{20-n} \sum_{0}^{n-11} A_k . 2^k$$

which gives
$$N = 2^{n-10}\left(N_1 + \frac{N_2}{2^{10}}\right)$$

The coefficient 2^{n-10} is common to all channels and therefore introduces no extra numerical work, especially as one is often interested only in the relative pulse distribution. The denominator of the second term is approximately 1000, and thus can be represented by a decimal point.

As an example take the sixteen-digit number

$$\begin{array}{lll} N = & 1\,1\,1\,0\,1\,1\,1\,0\,1\,0\,1\,0\,1\,1\,0\,1 & = 6\,1\,1\,0\,1 \\ N_1 = & 1\,1\,1\,0\,1\,1\,1\,0\,1\,0 & = 9\,5\,4 \\ N_2 = & 1\,0\,1\,1\,0\,1\,0\,0\,0\,0 & = 7\,2\,0 \end{array}$$

$$N \simeq 2^6 \times 954{\cdot}720 = 61\,102{\cdot}080$$

It is easy to show that the error introduced by the approx mation never exceeds the relative statistical error $1/\sqrt{N}$ provided that $n \leqslant 20$.

THEORY

An arbitrary positive integer N is expressed in binar notation as

$$N = \sum_{0}^{\infty} A_k . 2^k \qquad k = 0, 1, 2, \ldots$$

where the coefficients A_k can take the values 0 or 1. If w consider only numbers

$$N < 2^n$$

we have

$$N = \sum_{0}^{n-1} A_k . 2^k \qquad k = 0, 1, 2, \ldots n-1$$

Now, in the present problem, the set of values of A_k is giver and our task is to find a way to express N in decimal form This can be done by an apparatus able to occupy one of 2 possible states. Which state it occupies must depend on th given A_k set in a "one-to-one correspondence" manner. T each of the states, then, is assigned a positive integer member of the set of positive natural numbers. Let us stud the significance of only one of the A_k values, say A_v. W rewrite the expression for N as follows:

$$N = \sum_{0}^{n-1} A_k . 2^k = \sum_{0}^{v-1} A_k . 2^k + A_v . 2^v + 2^v \sum_{v+1}^{n-1} A_k . 2^{k-v} =$$
$$\sum_{0}^{v-1} A_k . 2^k + 2^v \left(A_v + \sum_{v+1}^{n-1} A_k . 2^{k-v}\right) = Y + 2^v .$$

where
$$Y < 2^v$$
$$X \begin{cases} \text{odd if } A_v = 1 \\ \text{even if } A_v = 0 \end{cases}$$

From the above expressions we find that if we know th value of A_v (0 or 1) we know also if X is odd or even, an we are thus able to *exclude* from the final result exactly ha of the 2^n possible values of N.

If we carry on this elimination process, considering th different values of A_k separately and in turn, we find that th N which corresponds to the given set of A_k values will never b among those eliminated. The A_k values corresponding t any other value of N must differ from the given set in a least one place and these unwanted values of N are therefor eliminated at least once.

---

* Hutchison, G. W., and Scarrot, G. C. *Phil. Mag.*, **42**, p. 792 (1951).

PRINCIPLE OF OPERATION

This elimination process can be carried out in the following ay. A number of holes (2^n) are drilled in a fixed brass ate, each representing one possible value of N. Over this ed “reference” plate and in close contact with it, is placed pack of n similar plates (selection plates), each of which s also 2^n holes, and can be independently moved into two ossible positions, called 0 and 1. To each of the holes in e reference plate is assigned a number, 0, 1, 2, . . . $2^n - 1$. e selection plates are numbered 0, 1, 2, . . . v . . $n-1$. e hole patterns in the selection plates are so arranged that, hen the plate v is in the 0 position, half of its holes coincide ith half of the holes in the reference plate, namely those hich represent the numbers

$$N = Y + 2^v . X_{even}$$

here $Y = 0, 1, 2, \ldots (2^v - 1)$

d $X = 0, 2, 4, \ldots (2^{n-v} - 2)$

he rest of the holes in the reference plate are covered, namely

$$N = Y + 2^v . X_{odd}$$

the disk v is moved to the 1 position the situation is reversed, that the holes corresponding to an even X are covered and e others left open.

It is easy to see that for all possible combinations of the ositions of the selection plates, one and only one of the oles in the reference plate will coincide with a hole in each the selection plates. If a lamp is placed on one side of e plate combination, this “coincidence” hole will be the nly one that leaves a free path for the light rays to produce bright spot on a screen. The number of this hole is the orrect answer.

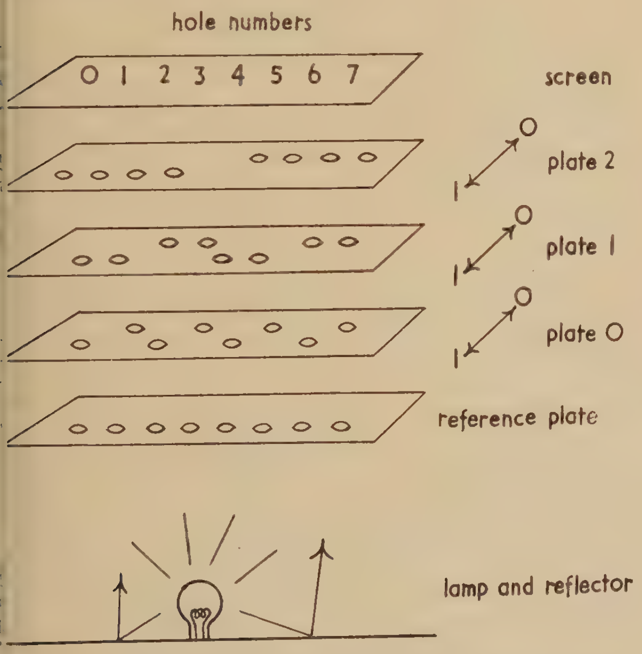


Fig. 1. The principle of operation. A bright spot on the screen indicates the decimal number corresponding to the binary number defined by the positions of the selection plates

The hole numbers are written on the screen in appropriate positions and notation.

Fig. 1 gives an example of a simple device employing this principle capable of converting numbers up to 7.

A TEN-DIGIT CONVERTER

A shallow brass box (150 × 210 × 30 mm) is divided into eight light-tight compartments, each painted inside with a diffuse reflecting white colour (Fig. 2). The “reference” plate, placed over the case, has 512 drilled holes (diameter 3 mm) arranged in a regular pattern with 25 rows and 21 columns.

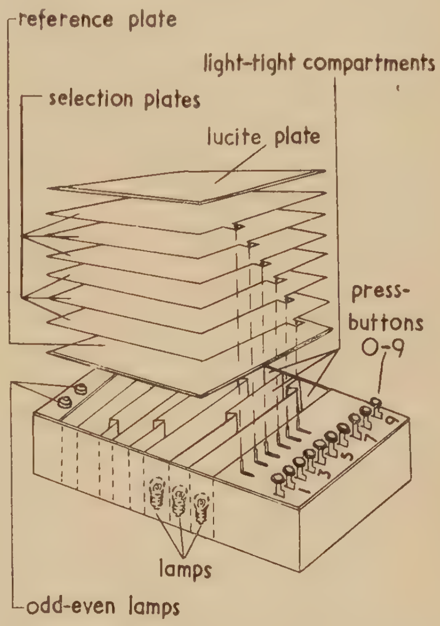


Fig. 2. Exploded view of ten-digit converter

The last column has only 12 holes. The box compartments are given a shape such that 64 holes fall over each of them. Each compartment can be illuminated, one at a time, by lamps selected by a switch pyramid, operated by three press-buttons numbered 9, 8 and 7.

Over the reference plate is placed a pack of six selection plates operated by the press-buttons 1–6. Over this pack is a green lucite plate, which serves as a light-diffuser and on which the hole numbers are engraved (in decimal notation). Each hole is given an even number 0–1022. The conversion capacity of this nine-digit converter is doubled by means of odd-even lamps operated by press-button 0.

When all buttons k are pressed for which $A_k = 1$, a bright spot on the screen will indicate an even number. $\sum_{1}^{n-1} A_k . 2^k$. The odd-even lamps tell whether this is the final result or if a 1 should be added.

ACKNOWLEDGEMENT

I wish to express my gratitude to the Director of the Research Institute of National Defence for permission to publish this communication.

The use of polarized light for the measurement of small angular displacements

By A. J. BARTLEY, B.Sc., King's College, University of Durham

[*Paper received* 9 *August*, 1955]

An investigation has been carried out into the use of polarized light for the measurement of small angular displacements of the order of one minute of arc. The basic technique is explained in detail and a description is given of a test rig which was built to determine the sensitivity of the method. The suitability of the system for dynamic measurements is discussed and various recommendations are made regarding possible future developments.

If a beam of light is polarized and then passed through an analyser the intensity of the light transmitted is a function of the relative angle of rotation between polarizer and analyser. If, therefore, the polarizer and analyser are mounted some distance apart on a shaft which is subject to torque, the twist in the shaft can be determined by measuring the intensity of the light transmitted.

METHOD OF APPLICATION

In applying this principle to the measurement of very small angles of twist it is insufficient merely to record the output illumination because the variations produced are insignificantly small relative to the initial level of illumination. It is therefore necessary to employ a system which measures the change in illumination as an absolute quantity. This can be achieved by comparing the intensity of the light leaving the analyser with that of a second beam of light from the same source. The initial intensity of illumination of both beams can be made identical, resulting in a balanced condition which will be upset whenever there is relative rotation between polarizer and analyser. The resulting unbalance can then be used to produce a signal that can be amplified and displayed on an oscilloscope or a pen recorder.

The technique can, in principle, be employed for dynamic as well as static measurements and a test rig was therefore built to enable both types of measurement to be performed.

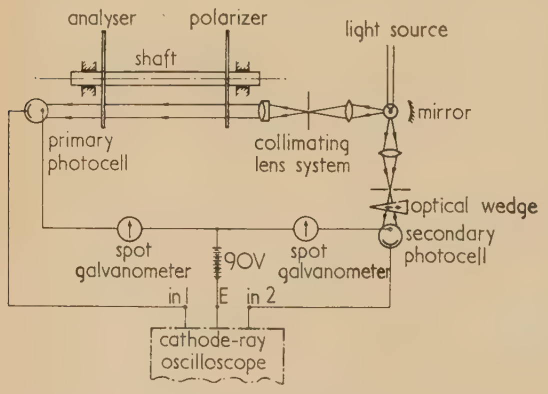


Fig. 1. Schematic arrangement of test rig

As the ultimate object of the work was to determine the suitability of the technique for an investigation into the performance characteristics of "constant" velocity universal joints, an attempt was made to simulate as closely as possible the type of layout which such an application would entail.

The resulting layout is shown schematically in Fig. 1.

DETAILS OF TEST RIG

Disks of Polaroid were used for the polarizer and anal and these were locked to a solid shaft which was supporte an engine lathe. The first disk (the polarizer) was moun in such a way that it could be unlocked and rotated rela to the second disk (the analyser) to enable static calibra tests to be performed. Coarse and fine angular adjustm mechanisms were fitted to the movable disk for this purp

The light source consisted of a 12 V, d.c., 100 W proje lamp which was voltage regulated and had a 1 Ω varia resistor fitted in series with it to enable the level of illumina to be varied. The lamp house was fitted to the lathe sad thus enabling the position of the lamp to be altered w desired.

The primary beam of light (i.e. the beam passing thro the Polaroid disks) was collimated and arranged paralle but offset from the axis of the shaft. The secondary be traversed a shorter path than the primary and it was the fore unnecessary to employ a collimating lens. Both bea were focused on to photocells of approximately sim characteristics and the photocell outputs were fed to balanced input side of a cathode-ray oscilloscope wherein signal was amplified and displayed as a spot trace.

The system was balanced initially by varying the amo of light falling on to the secondary photocell until its curr output was identical to that of the primary photocell; optical wedge was inserted in the secondary optical syst to enable this initial balance to be achieved.

INFRA-RED EFFECTS

Before considering the test results obtained some menti should be made of the effects of the infra-red radiation pres in the light beam. A considerable amount of this radiati is produced and, unlike the visible light, it is not polari by Polaroid.

As the photocells were sensitive to infra-red as well visible light it was necessary to absorb the infra-red radiati if maximum sensitivity was to be achieved. Heat absorb glass filters were therefore fitted to both optical systems a these were effective in removing approximately 90% of t infra-red radiation. More efficient filtration evidently cann be achieved without seriously reducing the level of visi illumination.

STATIC TESTS

The first static test was a routine procedure which enabl a characteristic curve for the Polaroid to be obtained (Fig. The polarizer was slowly rotated through 180° relative to t analyser by means of the coarse adjustment mechanism a the current output, in micro-amperes, of the primary phot cell, was recorded and plotted against relative angle tion. The resulting curve was, of course, sinusoidal in acter with two maxima at the 0° and 180° positions aroids parallel), and a minimum at the 90° position aroids crossed). At this latter position the photocell ut was 1·5 μA, even though this is theoretically the tion of light extinction. Part of this current output is to the fact that complete extinction of visible light does occur, but most of it is due to the presence of the unfiltered tion of the infra-red radiation.

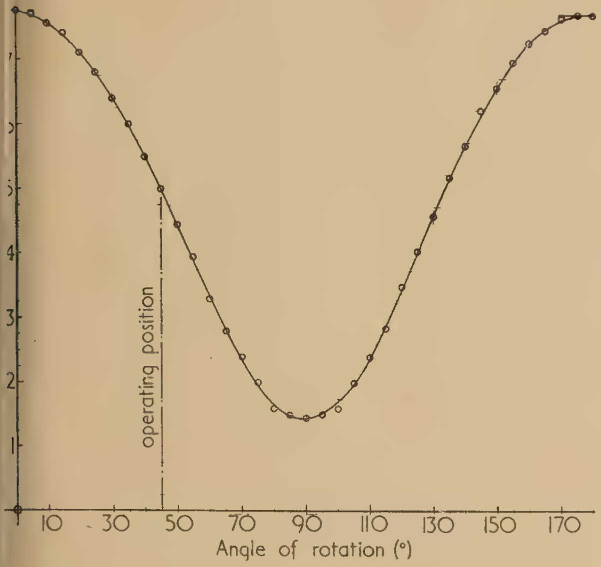


Fig. 2. Polaroid characteristic curve

The static calibration tests were carried out with the arizer rotated through an angle of 45° relative to the alyser, which is the operating position for maximum sitivity and of course corresponds to the position of ximum slope on the characteristic curve previously cussed.

The polarizer was rotated relative to the analyser by ans of the fine adjustment mechanism and the angle turned ough was measured by a form of autocollimator (Hilger gle Dekkor) which was focused on to a small reflector ed to the polarizer. In this way it was possible to measure all angles up to a maximum of one degree to an accuracy one minute of arc. The electronic circuit employed was that shown in Fig. 1 and the results were displayed on a Southern Instrument type oscilloscope.

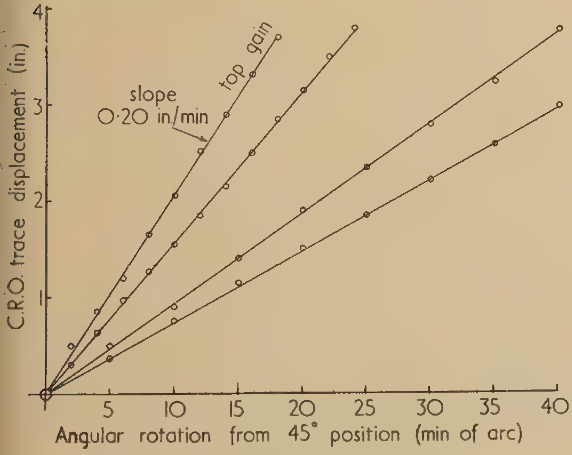


Fig. 3. Static calibration curves

A series of calibration curves were obtained for different sensitivities of measurement (Fig. 3). The range of angular movement considered was 0 to 40 min of arc although this range could be extended by reducing the sensitivity. As would be expected with such small angular ranges the response was virtually linear. At maximum sensitivity the slope of the curve was 0·20 in. trace movement per minute of arc. This was obtained using Mullard photocells type 20 C.G. with an anode supply voltage of 80 V and a nominal cathode current of 5 μA. Extensive tests showed that the repeatability of results was quite satisfactory, although a long term zero drift was evident.

DYNAMIC TESTS

As mentioned previously, there is no reason, in principle, why the technique should not be satisfactory for dynamic measurements. Tests proved unsatisfactory, however, owing to a defect which is peculiar to the type of layout employed.

It will be seen from Fig. 1 that, with this type of layout, it is essential that both polarizer and analyser have uniform light transmission characteristics because the primary photocell is continuously scanning different areas of the disks. Unfortunately, the light transmission characteristics of Polaroid are not uniform, except over small areas, and the deviation from uniformity is too erratic to allow compensation to be made. Selected portions of laboratory grade Polaroid were employed and it is unlikely that better material can be obtained at the present time.

If, therefore, the technique is to be applied successfully to dynamic measurements it will be necessary either to use polarizers which have uniform light transmission characteristics or to employ a system in which the uniformity of transmission is not a critical factor. Whilst it is possible to obtain better polarizing materials than Polaroid, such materials are not available in the form of disks of large area; consequently the second alternative appears to be the most promising.

ALTERNATIVE LAYOUTS

There are a number of alternative layouts available in which the non-uniformity of the polarizers is not a critical factor because the same areas of material are illuminated at all times.

The simplest application consists of a hollow shaft with the polarizer and analyser mounted internally and the light beam arranged coincident with the shaft axis. Small disks of Polaroid could be used for the polarizer and analyser although Nicol prisms would be preferable. The photocell and light housings would of course be fixed stationary at the ends of the shaft. This system could possibly be employed on a horizontal milling machine, with a hollow arbor, as a form of tool dynamometer.

If it is desired to employ a solid shaft then the polarizers, which may be segments of Polaroid or Nicol prisms, must be mounted externally. The photocells and light housing may be either rotating with the shaft or stationary. In the former case a continuous record of twist will be obtained but it will be necessary to employ three sets of slip rings and the shaft will probably have to be balanced dynamically. If the second alternative is adopted and the photocell and light housings are fixed stationary relative to the shaft then a continuous record of twist will not be obtained. Instead a series of discrete point observations would have to be made around the circumference of the shaft by indexing the polarizers through small angular increments—readings being taken every time the polarizers pass through the light beam.

Indexing may be made a manual operation but it would be preferable to make it an automatic process so that it could be performed whilst the shaft is rotating. This could possibly be achieved either by means of a ratchet and pawl device or by employing magslip drives to the segments. Irrespective of the indexing device employed, however, the discrete point observation method would only merit consideration if it were impossible to have the photocells and light source rotating with the shaft.

None of the above systems are being developed at present because they are not suitable for use on a universal joint test rig. The basic technique merits further development, however, because it offers a number of advantages over more conventional methods of dynamic angular measurement. It is not difficult to record angular movements of one minute of arc, the results can be obtained as a continuous record of twist and, most important of all, the sensitivity of respo unaffected by the speed of rotation. The hollow shaft s appears to be the most promising way of employin technique and it is hoped to develop this particular applic some time in the future.

ACKNOWLEDGEMENTS

The author wishes to thank the Director of the Mecha Engineering Research Laboratory, East Kilbride, for gra permission to publish this work which is sponsored b Department of Scientific and Industrial Research. Th are also due to Prof. A. F. Burstall of King's College provided the facilities for the work to be carried ou the author's colleagues Dr. J. S. Forsyth and Dr. R Gregory for their most valuable assistance and to Mu Ltd. and H. S. B. Meakin Ltd. who went to conside trouble to meet the author's requirements concerning p cells and Polaroid respectively.

A laboratory scale chill-casting vacuum induction furnace

By D. A. Craw, Ph.D.* and W. G. Henry, M.A.Sc., Ph.D., Division of Applied Chemistry,
National Research Council, Ottawa, Canada

[*Paper received* 19 *September*, 1955]

The details of the construction and operation of a simple laboratory scale induction furnace with a capacity of approximately 3 cm^3, which may be used at either low pressures (10^{-4} mm of mercury) or with an inert atmosphere is described. The furnace and induction unit are fitted to a tilting frame allowing the melt to be cast into a copper mould. Copper, silver, gold, magnesium and cadmium based alloys have been cast successfully with this apparatus.

For many metallurgical investigations it is desirable as an initial step to chill cast to prevent segregation, either in a vacuum, or in an inert atmosphere. The present apparatus was developed specifically to produce homogeneous ingots from which could be machined a specimen $\frac{5}{16}$ in. diameter and $\frac{13}{16}$ in. long for magnetic susceptibility investigations. Since the ingot size is suitable for both other physical measurements and equilibrium diagram work, it was felt worth while to describe the apparatus in detail.

GENERAL DESCRIPTION OF APPARATUS

A general view of the unit is shown in Fig. 1. It consists essentially of a tilting frame on which are mounted a small induction heating unit and a vacuum chamber containing the induction coil, crucible and mould.

The use of the induction coil inside the vacuum system permitted good coupling between the melt and the coil and allowed a small size of unit to be used.(1,2,3) The induction machine was a 2 kW Lepel, spark gap type. With this size of unit it became practical to rotate the furnace and unit together and thus maintain the lead length as short as possible.

The time required to raise the constituents of a melt in a non-conductive crucible from room temperature to melting point was of the order of two to three minutes. This rapid melting was particularly advantageous when one of constituents was volatile and made unnecessary provisio making additions to the melt by remote control. A fur advantage of induction heating was that rapid stirring induced in the melt.

The external dimensions were approximately 3 × 3 × excluding vacuum and gas purification systems, which ma suitable for research work as little laboratory space occupied.

A laboratory high vacuum furnace for small melts has b described previously,(4) but this furnace had no provision chill casting.

DETAILS OF CONSTRUCTION

The details of the vacuum chamber, furnace coil, cruc and mould assembly are shown in Fig. 2. The main vacu chamber was constructed from 6 in. diameter brass tub with $\frac{1}{2}$ in. wall thickness. The base and top rim were m from $\frac{1}{2}$ in. brass plate, silver-soldered on to the tube. standard groove to accommodate the $6\frac{1}{2}$ in. internal diam $\frac{1}{4}$ in. thick O-ring was machined into this top rim. overall dimensions of the vacuum chamber was $8\frac{1}{4} \times 8\frac{1}{4}$ The lid was held in place by eight wing nuts.

In order to keep the chamber cool to prevent deteriorat of the seals, five turns of $\frac{1}{4}$ in. diameter copper tubing through which water was passed, were soft-soldered to exterior. It was found advisable to turn this water off the end of a run prior to the removal of the lid in order prevent water condensation on days of high humidity.

---

* Now at Consolidated Mining and Smelting Co., Trail, British Columbia, Canada.

Note added in proof. It has been found that a reflecting shield of silver surrounding the induction coil increases the rate of heating appreciably.

he temperature and physical state of the melt was ervable through the viewing window *B*. For this purpose in. diameter hole was drilled into the lid directly above furnace coil. A standard O-ring groove was machined und this hole and a $1\frac{1}{4}$ in. diameter Pyrex disk held on to is O-ring by a brass flange. This could be removed easily r cleaning purposes. For alloys which melted below red eat, a 6 V, 18 W lamp *C* was used. The power for this as led through the brass lid by soft-soldering two metal-glass eed-through terminals" into $\frac{3}{8}$ in. holes in the lid.

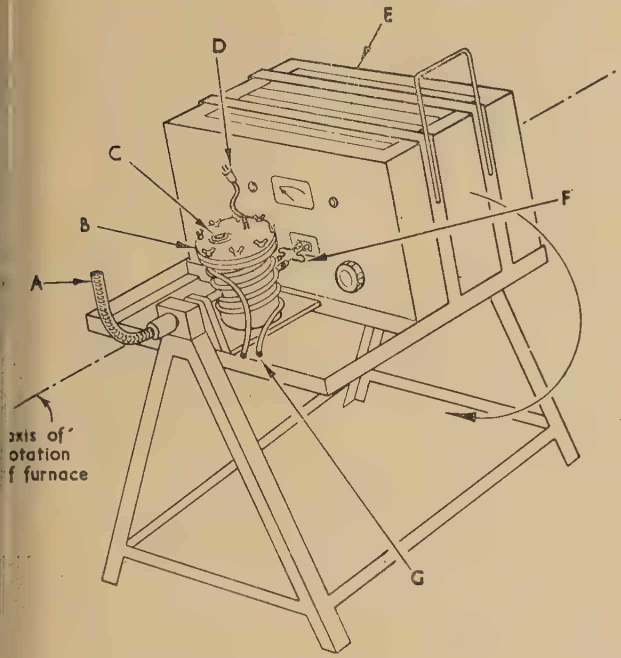


Fig. 1. Laboratory scale chill-casting vacuum induction furnace

A, Tygon vacuum lead; *B*, furnace; *C*, observation window; *D*, interior light connexion; *E*, 2 kW Lepel high-frequency unit; *F*, induction leads; *G*, cooling water coil.

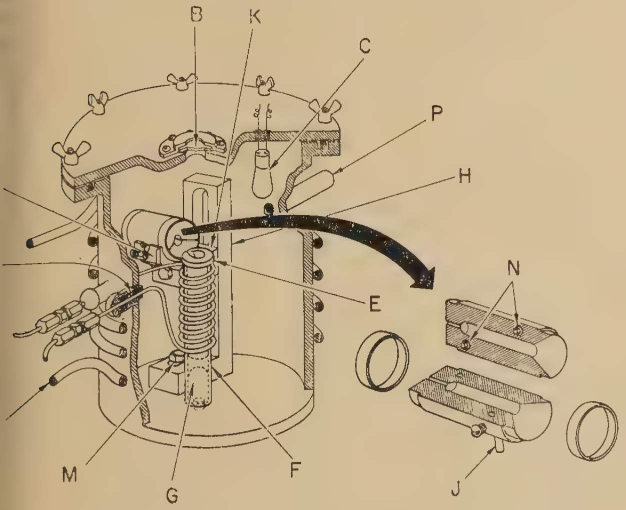


Fig. 2. Detailed view of vacuum chamber

The furnace coil consisted of nine turns of $\frac{1}{8}$ in. water-oled copper tubing and was $1\frac{3}{4}$ in. high and had an ternal diameter of 1 in. The copper tubing for the furnace coil was led through Bakelite insulators *D*, inside brass tubes and the junction made vacuum tight by heating this region gently and pouring molten Apiezon W40 black wax around the copper tubing and the recessed Bakelite. When the apparatus was first tried, sparking occurred between these leads and the vacuum chamber. By increasing the diameter of the Bakelite insulators to $\frac{3}{8}$ in. with $\frac{9}{64}$ in. diameter central hole, this difficulty was overcome.

The melting crucible *E* was separated from the furnace coil by a silica liner *F*, 1 in. outside diameter and $\frac{5}{32}$ in. wall thickness. A brass peg *G* fastened to the bottom of the chamber served both as a guide for the silica liner and as a support for a short length of quartz tubing on which rested the melting crucible. This length was adjusted so that the base of the crucible was at the bottom of the furnace coil.

Initially it was found difficult to get the metal to flow in a steady stream from the crucible. This trouble was overcome by two small corrections. The internal diameter of the melting crucible, which in an earlier model was $\frac{3}{8}$ in., was enlarged to $\frac{9}{16}$ in. and a pouring spout provided. Silica, graphite and iron crucibles have all been used with various alloys and in all cases a spout was necessary to give good castings.

The chill-casting mould consisted of a heavy cylindrical copper block (see Fig. 2) which was mounted on the adjustable stand *H* and arranged so that it would be approximately vertical when the metal was cast. The angle between the mould and the melting crucible varied from 95–115°, depending on the metal. The mould was fitted with a locating pin *J* $\frac{1}{2}$ in. long, $\frac{1}{4}$ in. diameter, which engaged a hole in the centre bottom of the cradle type bracket *K*. The mould was locked into position by moving slide *L*. The cradle type bracket could be raised or lowered and tilted through about 30° on the supporting stand. The position of the stand could be adjusted by loosening nut *M*.

In order to avoid the formation of a pipe, about 50% excess metal (included in the 3 cm^3) above that required to fill the mould, was used. No difficulties were encountered when casting in vacuum, but when an inert atmosphere was used it was found efficient to provide gas escape holes in the mould. For the heavy metals a $\frac{1}{16}$ in. hole in the bottom of the copper mould was sufficient, but for the magnesium base alloys it was found necessary to provide spacers *N* to allow the gas to escape more readily.

As the flexible vacuum connexion between the chamber and the vacuum system, Tygon tubing, $\frac{3}{8}$ in. internal diameter $\frac{1}{8}$ in. wall thickness with an internal coil of chromel wire to prevent collapsing under reduced pressures, was used. The tygon tubing was push-fitted to the brass vacuum lead *P*, $\frac{5}{8}$ in. outside diameter, fixed on the axis of rotation of the vacuum chamber and led out through a hollow bearing on the tilting frame.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. P. Langevin for preparation of the drawings and Mr. F. Liuzzo and Mr. E. Niman for construction.

REFERENCES

(1) Seybolt, A. U. *Metal Progress*, **50**, p. 1102 (1946).
(2) Kaufmann, A. R., and Gordon, E. *Metal Progress*, **52**, p. 387 (1947).
(3) Scaff, J. H., and Schumacher, E. E. *Metals and Alloys*, **7**, p. 204 (1936).
(4) Ehret, W. F., and Gurinsky, D. H. *Rev. Sci. Instrum.*, **12**, p. 151 (1941).

Apparatus for the electronic presentation of optical diffraction patterns

By A. W. Hanson, Ph.D., A.Inst.P., and A. Menarry, B.Sc.Tech., Grad.Inst.P., College of Technology, University of Manchester

[*Paper received* 8 *August*, 1955]

Apparatus has been built for the rapid visual presentation of small, rather faint optical diffraction patterns. An image of the diffraction pattern is focused on the photomosaic of a television camera tube capable of accumulating, for a period of about ten seconds, a corresponding charge pattern. This pattern is transferred to a storage device where it remains for a relatively long time during which it can be continuously presented on a television receiver. Examples of stored diffraction patterns are given.

In recent years the Physics Department of this College has been concerned with methods of crystal-structure determination which make use of the analogy between the diffraction of X-rays by a crystal lattice and the diffraction of light by a set of holes.(1,2) The most useful procedure is to prepare a two-dimensional model of a unit of a proposed crystal structure, and to compare its Fraunhofer diffraction pattern (or "optical transform") with the corresponding X-ray diffraction data. The model, which is simply a mask which contains an array of holes representing atomic positions, is very rapidly prepared with the aid of the pantograph punch described by Hughes and Taylor.(3) As a diffracting object, however, it is comparatively large, and a specially designed spectrometer(3) is used to observe its diffraction pattern. The pattern is small and for most models rather faint; it can be seen under a low-power microscope, but for adequate study it must be photographed and greatly enlarged.

Optical-transform methods are particularly valuable for the speed and logical continuity with which the effect of successive modifications of a proposed structure can be studied. It is, however, distracting to have to spend an hour on photographic procedures at each stage. The scope of the methods could be extended if images of the diffraction patterns, sufficiently large and bright for direct comparison with the X-ray diffraction data, could be presented fairly quickly. It was felt that such a presentation was required so urgently that it justified a considerable effort on the development of the necessary apparatus.

The apparatus which has been built makes extensive use of standard television equipment, and incorporates some devices developed (by Electric and Musical Industries Ltd.) for quite different purposes. In the section which follows, the several components will be discussed, but only in sufficient detail to show how their properties were used to produce a desired result. A brief account of a trial form of the apparatus has been published elsewhere.(4)

THE COMPONENTS

The first requirement was a suitable light-sensitive pick-up device to replace the photographic emulsion normally employed. The device adopted was the CPS Emitron (a television camera tube developed by Electric and Musical Industries Ltd.)(5) which is schematically represented in Fig. 1. Light entering the tube passes through the semi-transparent signal plate *A*, and is focused on the photomosaic *C*. This consists of a very large number of elements of photoemissive material, deposited on a transparent backing *B*, and insulated from one another. Photoelectrons emitted by the mosaic elements are conducted to the wall anode *D*, so that each element acquires positive charge at a rate depending on the intensity of the light received by it.

In normal television practice a low-velocity electron be is focused on the photomosaic, and continuously scans i a conventional raster. The function of the beam is periodic to discharge each element of the photomosaic to appr mately cathode potential (hence the designation "cath potential stabilized" or "CPS" Emitron). The pulse occur during the discharge of each element is communicated to signal plate by capacitance coupling, and appears on the of the first amplifier valve. The continuous sequence of s pulses constitutes the picture signal.

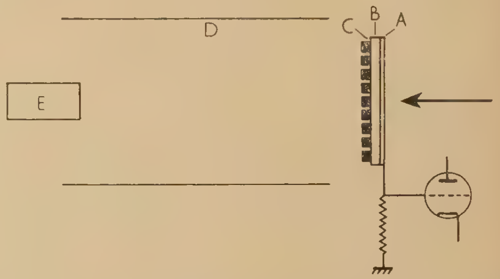


Fig. 1. Schematic diagram of the cathode potentia stabilized Emitron

A, signal plate; *B*, transparent backing; *C*, photomosaic *D*, wall anode; *E*, electron gun.

The sensitivity of the tube is limited by the noise of first amplifier valve; unless the signal is appreciably grea than this the picture is not intelligible. Signals produced the required diffraction patterns are well below the no level, and the tube cannot therefore be used in the usual w

It will be seen that the CPS Emitron is a charge-stora device; the size of the pulse produced by the discharge o particular mosaic element is a measure of the charge accum lated and stored by the element during the preceding ras period. This period is normally 1/25 s, but Professor McC has pointed out that selected tubes can be expected to sto charge for as long as ten seconds without appreciable leaka The method of using this property is to bias off the electr beam for ten seconds, and then suddenly to restore it. T result is a transient signal 250 times as great as the continuo signal derived from normal operation, and the effective ga in sensitivity makes the presentation of the diffraction patter possible.

A further storage device is required to allow the pictu corresponding to the transient signal from the camera tu to be studied at leisure. The device adopted was the E.M half-tone storage tube type VCRX350,(6) schematica represented in Fig. 2; it consists essentially of a stora electrode *A*, a writing section, and a reading section. T rage electrode is a fine metal mesh with an insulating layer the side adjacent to the writing section. This section tains an electron gun *B*, emitting a relatively high-velocity m which can be focused and made to scan the storage ctrode. The function of the beam is to produce charge on storage electrode; it can be modulated by the amplified nal from the camera tube, to produce on the storage ctrode a charge distribution corresponding to the informa- n accumulated on the photomosaic of the camera tube.

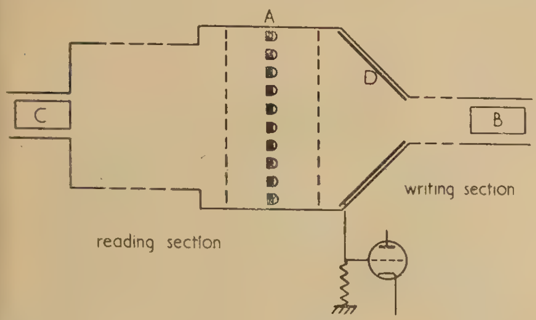


Fig. 2. Schematic diagram of storage tube type VCRX350

A, storage electrode; *B*, writing gun; *C*, reading gun; *D*, signal electrode.

The reading section is a modification of the CPS Emitron; low-velocity electron beam scans the storage electrode, and modulated by the charge on the insulating layer. The action of the beam which penetrates the mesh is collected the signal electrode *D* and appears as a modulated voltage cross the grid leak of the first amplifier valve. An important ature of the process is that the charge on the storage ectrode is dissipated only very slowly; a charge distribution n be continuously scanned (or "read") for as long as irty minutes without serious alteration.

The camera tube and the reading section of the storage tube e operated by an E.M.I. closed-circuit industrial television annel consisting of a control unit, a camera and a standard levision receiver. The control unit supplies all the wave- rms for the operation of the camera, and also presents the gnal output of the camera in a form suitable for the receiver nodulated radio-frequency, 405 lines interlaced scan, frames/s). The camera contains the camera tube, its focus d scan coils with some associated circuits, and a head nplifier with low-impedance output. The optical system ovided has been modified so that images received on the otomosaic are magnified by a factor of ten. The suppressor lses normally applied to the cathode of the camera tube ve been routed through a cathode-follower, to give the thode a low impedance to earth. This was done to reduce ansient variations of cathode potential caused by the storation of the scanning beam.

Focus and scan coils similar to those used for the camera be are used for the reading section of the storage tube; anning currents are obtained from the camera when quired. Modified television-receiver equipment provides e scan coils and time base for the writing section; the nchronizing waveform is derived from the control unit.

A "writing" amplifier, with a total swing of about forty lts was built for modulating the writing beam, and a eading" head-amplifier for the amplification of the minute gnal output of the reading section of the storage tube.

Two precautions must be taken for the efficient transfer of information from the camera tube to the storage electrode. First, the restoration of the scanning beam in the camera must be effected at the beginning of a frame period, in order to prevent the appearance of switching phenomena in the picture. Second, the gun of the writing section must be prevented from writing except when the information is actually being transferred. The purpose of concentrating the signal corresponding to a ten-second exposure into a period of 1/25 s is to improve the ratio of signal to amplifier noise, but clearly maximum improvement will not be realized if the amplifier noise is recorded on the storage electrode for the rest of the ten-second period.

The requirements were met by the construction of a circuit for the application of simultaneous brightener pulses to both electron guns. The circuit uses a synchronizing waveform derived from the control unit; on the operation of a switch, it generates a single rectangular pulse, of about sixty volts amplitude, exactly coincident with a frame scan period. The last stage of the circuit is a cathode-follower with two outputs, the level of one of which is adjustable. The fixed-level output is condenser-coupled to the grid of the writing gun; the other is suitably adjusted and, when it is required, is coupled directly to the grid of the camera tube.

LAYOUT AND OPERATION

The individual components are arranged in the four main units indicated in Fig. 3.

The camera unit contains the modified television camera *A*, the brightener pulse circuit *B*, and a small control panel *C*. The controls allow the switching of scanning currents (either to the camera or to the storage unit), continuous or pulsed operation of the camera tube, and various alternative cross-connexions among the several amplifiers.

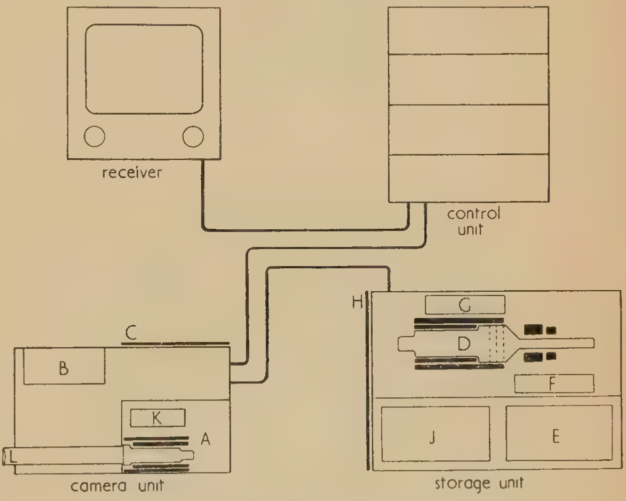


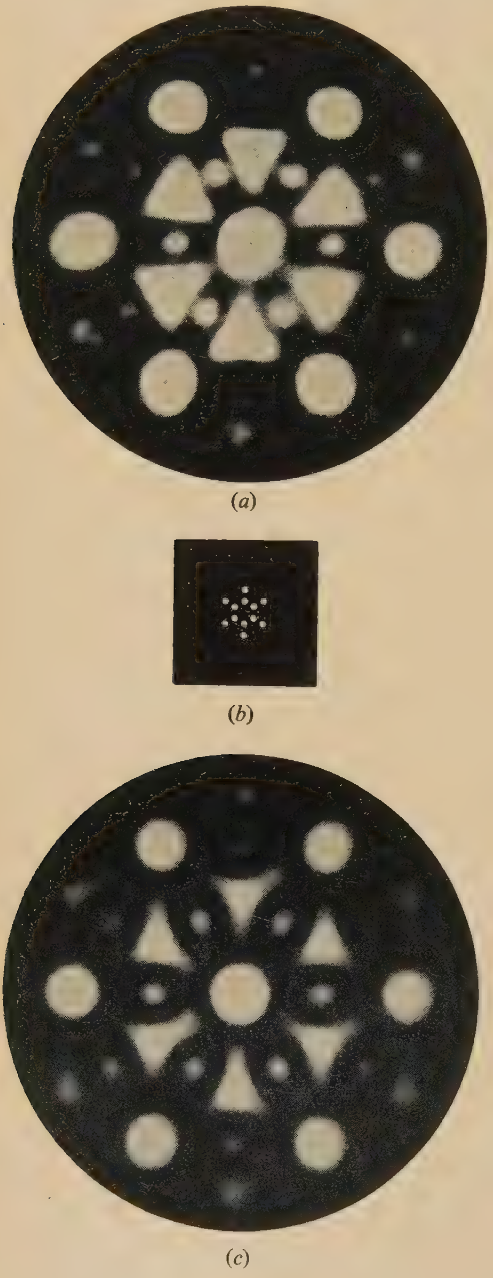
Fig. 3. Layout of apparatus

A, camera; *B*, brightener-pulse circuit; *C*, control panel; *D*, storage tube; *E*, writing time base; *F*, writing amplifier; *G*, reading head-amplifier; *H*, control panel; *J*, power supplies; *K*, camera head-amplifier; *L*, camera lens.

The storage unit contains the storage tube *D* and its associated focus and scan coils, the writing time base *E*, the writing amplifier *F*, the reading head-amplifier *G*, power supplies, and a control panel *H*. The controls permit the adjustment of the various potentials for the efficient viewing and erasure of stored patterns.

The control unit and receiver are used without modification, and the apparatus is so arranged that all the commonly-used controls are readily accessible to the operator.

When a diffraction pattern is to be examined, its enlarged image is focused on the photomosaic of the camera tube, and scanning currents are directed to the camera. Normal operating potential is applied to the grid of the camera tube, so that the photomosaic is brought to a steady state, and the output of the camera head-amplifier is directed to the writing amplifier. The appropriate output of the brightener-pulse circuit is applied to the grid of the camera tube; since this circuit is normally quiescent the effect is to bias off the scanning beam, and thus to allow charge to accumulat the photomosaic. After an interval of not more than seconds, the brightener-pulse circuit is operated, causing photomosaic to be discharged and the associated signal t amplified and applied to the cathode of the writing Through the operation of the brightener-pulse circuit, gun is in a condition to write, and the required charge pat is therefore produced on the storage electrode. A varia of this procedure is to apply the output of the camera h amplifier to the control unit, so that the pattern app momentarily on the receiver. This is useful for prelimi adjustment of the apparatus.



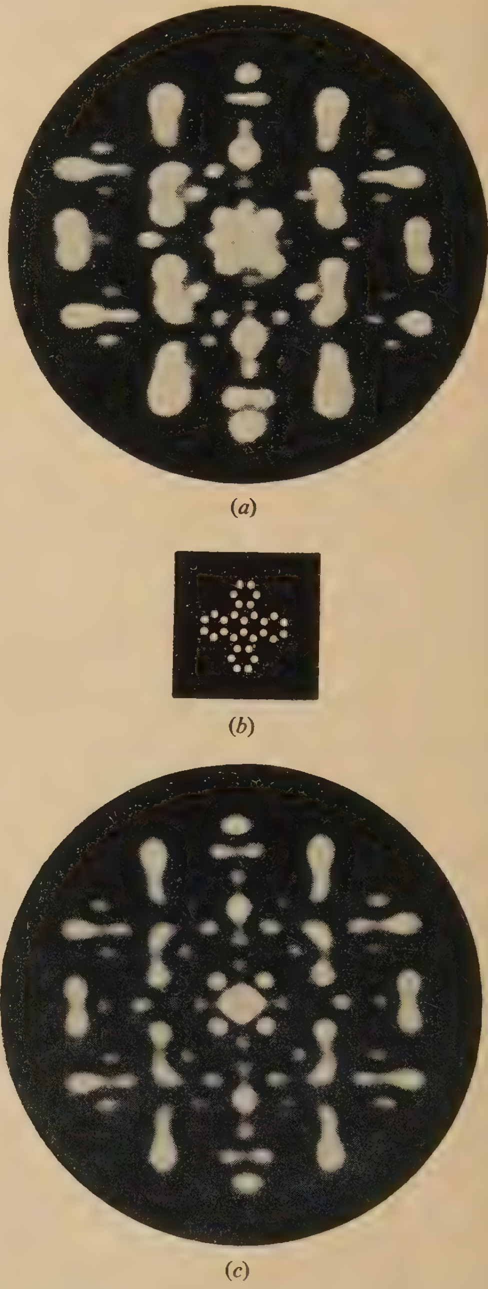
(*a*)

(*b*)

(*c*)

Fig. 4. Comparison of the two methods of presentation for an idealized molecule of hexamethylbenzene

(*a*) Stored facsimile of diffraction pattern; (*b*) diffracting object (an idealized molecule of hexamethylbenzene); (*c*) photograph of diffraction pattern.



(*a*)

(*b*)

(*c*)

Fig. 5. Comparison of the two methods of presentation for an idealized molecule of diphenylene naphthacene

(*a*) Stored facsimile of diffraction pattern; (*b*) diffracting object (an idealized molecule of diphenylene naphthacene); (*c*) photograph of diffraction pattern.

en the charge pattern has been stored, the scanning nts are directed to the scan coils of the reading section, correct potentials are applied to the appropriate elec- s. The output of the reading head-amplifier is directed control unit, so that a facsimile of the original diffraction rn appears on the receiver, to be studied at leisure. the pattern is no longer required, it is erased by the orary alteration of one electrode potential.

PERFORMANCE OF THE APPARATUS

e facsimiles of two typical diffraction patterns, as they ared on the receiver, are shown in Figs. 4 and 5. The cting objects and enlarged photographs of the actual ction patterns are also shown. Fig. 4(*a*) shows the t obtained with a simple model; virtually all the detail esent, and the facsimile would be adequate for most oses. Fig. 5(*a*) relates to a more complicated model, and esents a more searching test of the apparatus. It can be that there is some non-uniformity, and that some of the er detail is missing. However, this facsimile would be uate for many purposes, and it possesses the decisive ntage that its "processing time" is negligible. The entional photograph is unquestionably better, but ably only in special circumstances would it be worth ing for.

is felt that the apparatus is sufficiently developed to be l for crystallographic problems, and the intention is now se it even if, as the examples show, the facsimiles are still ior to the photographs. It is encouraging to recall the dy improvement in photographic techniques which has n place since the original diffraction spectrometer was , and it seems reasonable to suppose that comparable ovements will be achieved with the electronic presenta- apparatus when some experience of its application to lems has been gained.

ACKNOWLEDGEMENTS

The authors are deeply conscious of the value of the assistance they have received from many quarters, and must acknowledge, however inadequately, their indebtedness to the following: Professor J. D. McGee, of Imperial College, Mr. J. A. Lodge and Mr. R. S. Webley, of Electric and Musical Industries Ltd., and Dr. B. V. Bowden, Principal of the College of Technology, for essential ideas and advice; Mr. V. H. Attree, of the Electrical Engineering Department, for designing the pulse brightener circuit, and for other assistance; Dr. C. A. Taylor and Professor H. Lipson, of the Physics Department, for advice and encouragement; Imperial Chemical Industries Ltd., for generous financial assistance; Electric and Musical Industries Ltd., for the loan of the storage tube, and for other assistance; Messrs. Ferranti Ltd., for the gift of some equipment. In addition, one of us (A. W. H.) gratefully acknowledges tenure of an I.C.I. Fellowship in the University of Manchester, and the other (A. M.) of a maintenance grant from the Department of Scientific and Industrial Research.

REFERENCES

(1) HANSON, A. W., LIPSON, H., and TAYLOR, C. A. *Proc. Roy. Soc. A*, **218**, p. 371 (1953).
(2) HANSON, A. W., and LIPSON, H. *Acta Cryst.*, **5**, p. 362 (1952).
(3) HUGHES, W., and TAYLOR, C. A. *J. Sci. Instrum.*, **30**, p. 105 (1953).
(4) HANSON, A. W., TAYLOR, C. A., and LIPSON, H. *Proceedings of Manchester Symposium on Astronomical Optics* (Amsterdam: North Holland Publishing Co., to be published).
(5) MCGEE, J. D. *Proc. Instn Elect. Engrs*, **97** (III), p. 377 (1950).
(6) WEBLEY, R. S., LUBSZYNSKI, H. G., and LODGE, J. A. *Proc. Instn Elect. Engrs*, **102B**, p. 401 (1955).

A constant temperature solubility cell or reaction vessel for a Beckman quartz spectrophotometer*

By D. N. GLEW, Ph.D. and R. E. ROBERTSON, Ph.D., Division of Pure Chemistry,
National Research Council, Ottawa, Canada

[*Paper first received* 28 *April, and in final form* 21 *September*, 1955]

An adapter is described which permits the use of the Beckman DU spectrophotometer for the continuous study of equilibria and reaction kinetics in solution. The design permits the optical density measurement at closely controlled temperatures, while retaining simplicity of assembly and operation.

use of the Beckman DU spectrophotometer as an ytical tool in the study of equilibria and kinetics is well wn. Frequently, however, inherent convenience and racy are diminished through the use of test sampling niques.(1,2,3) Existing designs for the temperature rol of the test cells in the Beckman spectrophotometer been published by Bell and Stryker(4) and by Vestin, und and Ralf.(5) None of these designs was suitable our purposes since it was not possible to stir the solutions inuously while the optical density was measured. In paper an attachment is described which will permit the ument to be used as a continuous detector for either libria or kinetic studies with close temperature control. attachment is a modification of earlier designs from this ratory,(6) and by Weinberger and MacKay.(7)

The attachment, which weighs 5 lb, consists of a thermostated glass vessel *A* illustrated in Fig. 1, containing the bulk of the solution, and a thermostated box, shown in Fig. 2, which surrounds the one centimetre test and standard quartz absorption cells *B*. The solution is circulated from the glass vessel through the test quartz cell and back to the vessel. The light absorption of the solution passing through the test cell is measured and compared with that of the standard cell which contains the solvent only. The thermostated box reduces the heat losses of the circulating liquid in the test cell and maintains the standard cell at the same temperature. A pipe *C* leading thermostated gas into the central portion of the box is provided to avoid clouding of the quartz cell faces when the apparatus is used below room temperature.

The upper glass vessel (Fig. 1) is heated to a constant temperature by passing water from a thermostat through its outer jacket. The central part of this vessel contains the test solution which is circulated in the closed circuit by means of a glass centrifugal pump *D* driven by a magnetic induction motor.(8) The rotor of the pump consists of a small copper cylinder sealed inside a close-fitting glass capsule fused to a glass rod, to the lower end of which the pump vanes are attached, the whole assembly being mounted on terminal Teflon bearings. The upper cap of the glass vessel containing the upper bearing can be removed so that the rotor assembly can be taken out and the apparatus cleaned. The lower end of the vessel provides the outer casing of the centrifugal pump leading directly to the quartz test cell, from which the liquid returns through a tube inside the heating jacket back into the centre of the vessel. The glass vessel is clamped in position by a gate in a machined Duralumin support block, which is in turn supported at the proper height by a rod mounted on the baseplate. This Duralumin support block also serves as a mount for the motor stator. The gate, lined with gum rubber, is the only rigid fixture supporting the cell. The lower tubes from the pump to the cell are bound with glass tape to avoid crushing by the metal of the plate with which they are in contact. The space between the tubes and the plate is filled with plastic wood to reduce heat losses and to position the lower end of the vessel. The whole of the glass vessel below the support arm is covered with asbestos sheet which is uniformly wound with a Nichrome heating coil used at higher temperatures to reduce the heat losses of the circulating constant-temperature water. The vessel and heating coil are enclosed in a waterproofed asbestos box loosely packed with glass wool to provide further heat insulation.

---

* N.R.C. Contribution No. 3823.

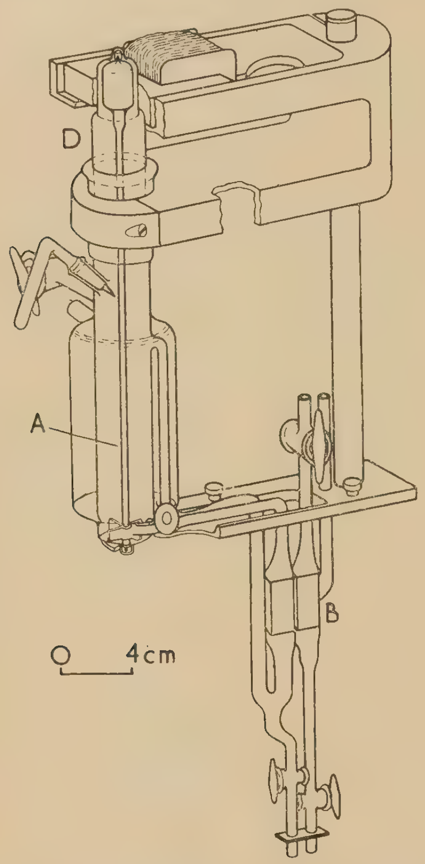


Fig. 1. Stirred reaction vessel with support and reference cell

The lower thermostated box (Fig. 2) is kept at co temperature by the circulation of water from a therm through its inner surfaces. The two large outer sides box, faced with Teflon sheet, are machined to form a com bearing and insulating surface for the four brass rails are fixed to the outer container. To position either th cell or the standard cell in the light beam, the inner l moved to terminal stops along the brass rails $E^{(7)}$ by a machined screw *F*. The front and back of the inner bo all open metallic faces of the container are covered insulating felt to reduce the heat losses.

The thermostated box container (Fig. 2) is attached optical system of the Beckman spectrophotometer by brass bolts in the normal position. The whole unit sho Fig. 1 is now mounted on the thermostated box, wher secured in position by two knurled nuts *G*. The simp of this assembly is of particular advantage when it is nece to service the spectrophotometer or desirable to fill vessel away from the thermostat. The glass vessel, test standard cells, and the thermostated box now move single unit, the large screw being used to move the assembly with respect to the spectrophotometer.

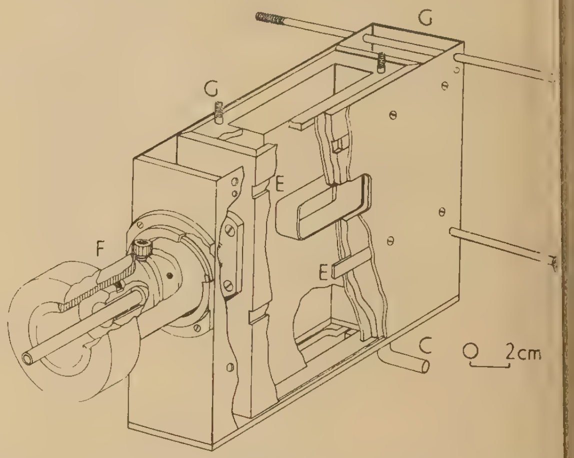


Fig. 2. Thermostated adapter for Beckman DU spect photometer

Temperature variation of a water solution inside the as indicated by a thermistor was less than ±0·01° C at and less than ±0·02° C at 75° C. In these tests the exp head of the cell was merely insulated with glass wool. B control than indicated by the above limits was possible w the loss or radiant heat was reduced through additio controlled subsidiary heating at the exposed head of glass cell.

ACKNOWLEDGEMENTS

We are indebted to Mr. G. S. Allan for assistance i design of the mechanical parts and to Mr. J. G. LaBre the machinist. Our thanks are also due to Mr. George E who produced the glass vessel and quartz cells to fit the assembly.

REFERENCES

(1) Andrews, L. J., and Keefer, R. M. *J. Amer. C Soc.*, **71**, p. 3644 (1949).
(2) Bohon, R. L., and Claussen, W. F. *J. Amer. Chem.* **73**, p. 1571 (1951).
(3) Herington, E. F. G., and Kynaston, W. *J. Chem.* p. 3137 (1952).

ELL, P. H., and STRYKER, C. R. *Science*, **105**, p. 415 (1947).

ESTIN, R., OSTLUND, B., and RALF, E. *Instruments and Measurements Conference, Stockholm*, p. 37 (Stockholm: Royal Swedish Academy of Engineering Sciences, 1949).

(6) WILLI, A. V., and ROBERTSON, R. E. *Canad. J. Chem.*, **31**, p. 361 (1953).

(7) WEINBERGER, M. A., and MACKAY, A. F. *J. Amer. Chem. Soc.*, **77**, p. 1321 (1955).

(8) MICHELL, D. *J. Appl. Chem.*, **1** (Supp. 1). p. *S*8 (1951).

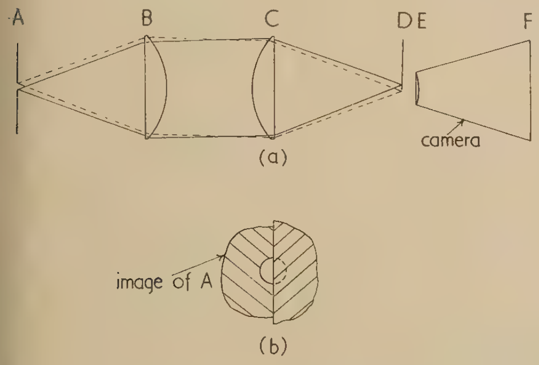
A wide range Schlieren system

By H. JEFFREE, B.Sc., A.F.R.Ae.S., Vickers-Armstrongs (Aircraft) Ltd., Weybridge, Surrey

[*Paper received* 12 *September*, 1955]

The Schlieren optical system is well known to be a simple and sensitive method of displaying variations in air density, such as are found, for instance, in the flow of air through a wind tunnel. Normally, a choice must be made between high sensitivity to show fine detail and long range so that main features are not lost or distorted. Methods are given here whereby both high sensitivity and fine detail are obtained simultaneously. It is even possible to obtain unambiguous measurements through glass windows not initially designed for Schlieren work; or to show fine striations in all parts of a sheet of glass which has also larger surface irregularities.

ormal Schlieren system is, perhaps, most easily explained considering the particular case shown in Fig. 1(*a*). Light ing through an aperture *A* is rendered approximately llel by lens *B*; and focused by lens *C* to form an image in the plane *D*. This plane *D* is half transparent and opaque; the junction being a straight line perpendicular he plane of the paper and known as the knife edge. ond *D* the light passes into the observing system *F* which be the observer's eye, a telescope or a camera as shown.



ig. 1. (*a*) Diagrammatic Schlieren system. (*b*) Section at *D*

n the absence of any disturbance between *B* and *C* all ts of the field of view of the camera are uniformly lit by t passing through that half of the image of *A* which lies the knife edge, as shown in Fig. 1(*b*). This D-shaped ge forms a stop to the viewing system.

f the space between *B* and *C* contains variations of air sity equivalent to a prism as shown in Fig. 2(*a*), then the earance of the plane *D* will be as in Fig. 2(*b*), with the le of the image of the light source aperture lying in the r. Conversely, if the air density variations were in the osite sense, the image of the aperture would be displaced to the knife edge as in Fig. 2(*c*), and light would be wholly off. Density wedges of lower intensity will give lesser vements of the image at *D* and effective variations of stop as shown at Fig. 2(*d*) and (*e*).

It is seen, therefore, that the effective stop of the camera lens *E* is varied by density gradients in the air between *B* and *C*, and that if these gradients occur as small local disturbances, the image at *F* will show variations of light and dark representing the degree of wedge disturbance through which any particular part of the light has passed.

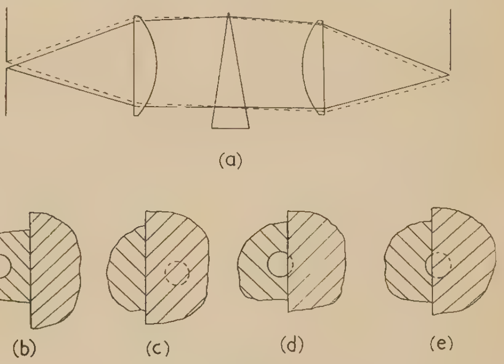


Fig. 2. (*a*) Diagram including prismatic disturbance. (*b*) Section at *D* with strong positive prism. (*c*) Section at *D* with strong negative prism. (*d*) Section at *D* with weak positive prism. (*e*) Section at *D* with weak negative prism

In the simple form it is obvious that once the image of the aperture has been deflected completely on to or completely off the knife edge, no further information is recorded on the screen at *F*. This state of affairs can be improved by using an elongated exponential shaped light source as shown in Fig. 3 or by using a wedge filter instead of a knife edge at *D*,

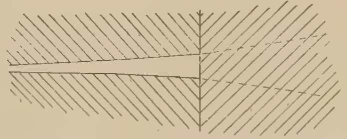


Fig. 3. Exponential slit light source

but this still only allows one pass from dark to light to convey the information required.

In the new system, the source of light at *A* is replaced by a rectangular spectrum coloured source as in Fig. 4(*a*), and the knife edge at *D* is replaced by a grating, the pitch of which is approximately equal to the effective width of the source. Suppose the image of the source to fall centrally on a bar of the grating, only the blue and red ends of the spectrum will get through and the lenses will appear filled with purple light. A displacement to the left [as viewed in Fig. 4(*b*)] will cause the light to grow more blue and through blue—green—yellow—orange to red; and back to purple once more when the deflexion is equal to the pitch of the grating. Further deflexion causes it to pass through the same colour cycle over and over again and, each time round, any small change of deflexion still causes an appreciable colour change. Displacements to the right show the reverse order of colour.

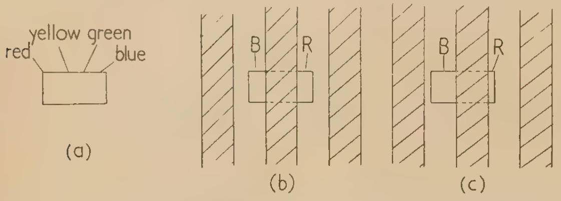


Fig. 4. (*a*) Spectrum light source. (*b*) and (*c*) Sections at *D* with spectrum light source at *A* and grating at *D*

The light source is easily made by taking an electric lamp with a short straight filament, seen end on in Fig. 5, at the focus of a photographic lens, the light then passing through a prism and through a second photographic lens to form the desired spectrum at *A*.

Since the grating on which the image is received is repetitive it is permissible for the source to be so also, and in some cases this may be beneficial. A lamp manufacturer could probably be found who would produce, say, a 100 W lamp, the light source of which consisted of several straight parallel coils equally spaced in the same plane, and with a bulb arranged to avoid undesirable reflected images. Such a lamp would simply replace the single filament one shown. Equally the source could be a series of lines ruled in coloured dyes on a gelatine base, or normal gelatine tricolour filters cut into strips and mounted on a glass slide, or a colour photograph of a series of exposures of a line of light spread to a spectrum (by means of a prism). Lighting can then be by any diffuse source, behind the coloured screen.

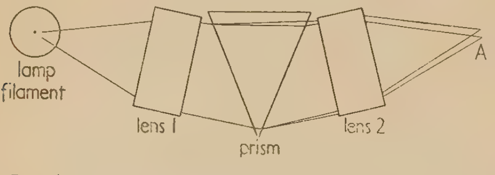


Fig. 5. Arrangement of components for producing spectrum light source

Mention has been made of the fact that the image may be deflected by the non-uniform air through many cycles of change. As the refractive index for air is not constant for all wavelengths, the cycles of change are not identical as the effective width of the spectrum is increased for deflexions one way and reduced for deflexions the other way, but this change is about 3% per cycle and its effect is not apparent, being merely a slight loss in the intensity of the colour seen.

Fig. 6 shows the actual details of a layout for direct
use. The lamp is a 3 W, 4 V sound film "exciter" lamp
approximately 0·006 × 0·15 in. filament. Lenses, Ross
angle X press; prism, 45° crown glass; effective wid
spectrum about $\frac{1}{16}$ in.

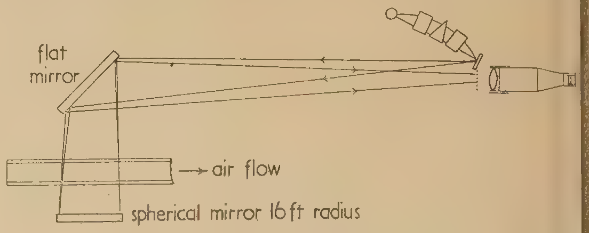


Fig. 6. Layout as used for a wind tunnel

Alternatively the light source could have been the bare
at *A* and a prism of small angle could be added in fro
the circular mirror.

In some cases it may be advantageous to replace
grating of uniform parallel lines by one in which the t
mission bands vary exponentially in width from to
bottom. Using such a grating, shown in Fig. 7, la
deflexions are still shown in detail by the colour of the i
but vertical deflexions also are indicated, as in no
Schlieren, by changes in intensity although only one
cycle of change is obtained. At the expense of some s
ambiguity in interpretation of the results these ve
deflexions can also be made repetitive by a screen conta
repetitive exponential slits opening at a greater rate t
those of Fig. 7(*a*); this is shown in Fig. 7(*b*). The ambig
can, of course, be resolved by moving the screen vertic
through half a vertical pitch, as it only occurs when
image of the light falls about on the band of discontin
between the exponential curves.

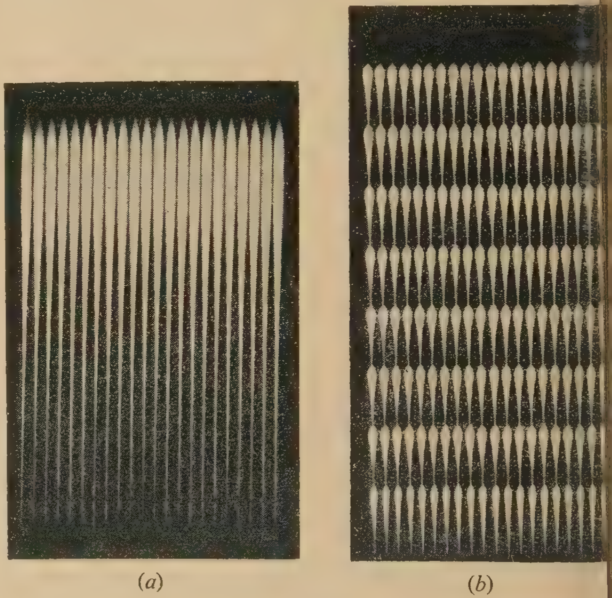


Fig. 7. (*a*) Grating of single pass exponential slot
(*b*) Grating of multiple pass exponential slots

ACKNOWLEDGEMENTS

The author wishes to thank Vickers-Armstrongs (Aircr
Ltd. for permission to publish this paper.

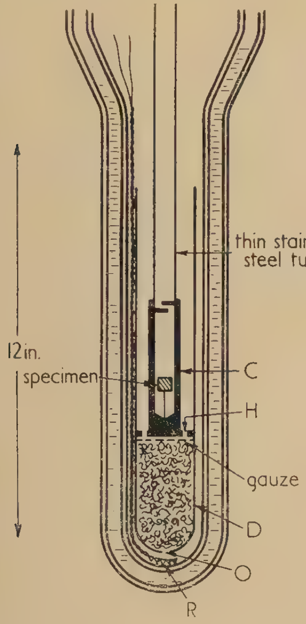
Laboratory and workshop notes

imple desorption system for obtaining temperatures above that of liquid helium

y A. C. ROSE-INNES, M.A., D.Phil., and R. F. BROOM,
.Sc., Services Electronics Research Laboratory, Baldock,
Herts.

[*Note first received* 21 *June, and in final form* 3 *August*, 1955]

a cryostat which uses liquid helium shielded by liquid rgen we have been able to obtain and hold temperatures ween 90 and 4·2° K by a simple device based on Simon's orption method of obtaining low temperatures.* Simon's thod was devised to *reach* helium temperatures starting m liquid hydrogen temperatures. We, however, use *id* helium to cool down the apparatus and saturate the rcoal, and only use the desorption of helium gas to obtain nperatures above the boiling point of helium. This, of rse, makes for simpler apparatus. With our device nperatures above 4·2° K can be obtained without any high uum or electrical arrangements, other than the rotary mp used to pump the liquid helium.



Desorption system for use with liquid helium

he figure shows an arrangement suitable for use in a iled" Dewar vessel between magnet pole pieces. The cimen is mounted inside the copper calorimeter *C*, and a copper can *D* containing activated charcoal is attached the bottom of the calorimeter. The top of this can is forated by a ring of large holes. In our apparatus we have d about 60 g of granulated activated animal charcoal itish Drug Houses Ltd.).

he inner Dewar vessel is filled with liquid helium and nperatures below 4·2° K are obtained by reducing the ssure over the helium in the usual way. To obtain higher nperatures the remaining liquid helium is first boiled off at nospheric pressure by the electrical heater *R*. A small hole *O* in the bottom of the can *D* allows the surplus liquid helium to drain out, leaving the charcoal saturated with adsorbed helium at atmospheric pressure.

When all the liquid helium has gone, the temperature of the calorimeter will rise due to heat leaking in: this rise can be accelerated by the heater *R*. When the desired temperature has been reached, it can be held constant by pumping the inner Dewar vessel through a needle-valve. The helium gas escapes through the holes *H*, and the heat of desorption balances the heat leaking in. The temperature can be maintained constant for long periods by slight adjustment of the pumping speed. For example, it was possible to hold a temperature of 21° K for over half an hour when 100 mW were being generated in the calorimeter in addition to the normal heat leak.

An additional advantage of the system is that the saturated charcoal has a large heat capacity and so the temperature rises only very slowly even when the charcoal is not being pumped. In a typical experiment the calorimeter took thirty minutes to warm from 4·2 to 5° K. This allows continuously variable temperature measurements to be carried out.

Acknowledgement is made to the Admiralty for permission to publish this note.

---

* SIMON, F. E. *Physica*, **4**, p. 879 (1937).

A two-way tap for continuous operation

By F. A. GRIMES, Bedford College, University of London

[*Note first received* 11 *May, and in final form* 9 *June*, 1955]

In a recent paper by Little and Smith* on the high frequency ionic conductivity of potassium chloride solutions, an apparatus was described in which two liquids were made to flow alternately through a small bore quartz tube. The experimental requirements were threefold, namely:

(i) that the tap should operate continuously for long periods;
(ii) that an accurate switching cycle should be maintained;
(iii) that a minimum of inter-mixing of the liquids should occur.

The final design consisted of a T-piece, accurately fitted to the top of the quartz flow tube, the two inlets of which communicated with the two liquid reservoirs.

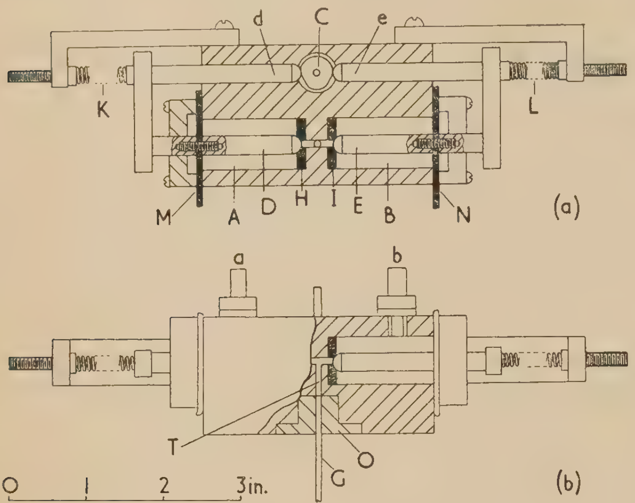
During a cycle of operation, one limb of the T-piece was closed by means of a phosphor-bronze ball, while one liquid flowed through the other limb. This limb was then closed by another ball valve before the ball closing the other limb was released. A complete cycle consisted of two flow periods of three seconds, separated by two periods of one second during which no flow took place. This was achieved by using a cam to operate the ball valves, each being independently sprung into their seatings by external springs. The constructional details and the action of the cam are shown in the figure.

The liquids enter the tap through the inlets *a* and *b* which connect with the reservoirs *A* and *B* respectively. As the cam *C* rotates, plungers *d* and *e* are alternately moved in and out, simultaneously operating the ball valve shafts *D* and *E*, thus allowing the liquids in the reservoirs to flow alternately *via* the T-piece *T* through the quartz tube *G*. The latter is firmly fitted to the outlet of the T-piece by means of a polythene bush *O*.

---

* LITTLE, V. I., and SMITH, V. *Proc. Phys. Soc.* [*London*] *B*, **68**, p. 65 (1955).

The ball valves form a seal in polythene seatings *H* and *I*, and as the cam *C* rotates, are returned to their seatings by the external retaining springs *K* and *L*.



Constructional details of two-way tap showing action of the cam

(*a*) Plan view. (*b*) Front view.

The rubber seals *M* and *N* keep the reservoirs *A* and *B* liquid tight, while allowing sufficient movement of the ball valve shafts *D* and *E* to operate the tap efficiently.

A thyratron index and time-marking unit

By R. B. Morrison, B.Sc., Ph.D., Sir John Cass College, London, E.C.3

[*Note received* 4 *July*, 1955]

When photographing transient waveforms displayed on a cathode-ray tube screen, it is often desirable to index the records automatically. This may be done by using the transient itself to operate a lamp illuminating an electromagnetic counter, followed by a rotation of the counter wheel through one digit. An index number can thus be photographed simultaneously with the transient waveform. It is important that these two operations should not occur simultaneously, as the numeral wheel would be illuminated while in motion and a blurred image would result. Further, a momentary illumination may not give adequate exposure. The best method is to delay the counter operation until the illumination of a stationary numeral is adequate. This requires the transient to initiate a sequence of two operations separated by a selected time interval.

A further requirement when recording cathode-ray tube traces on moving film is a suitable time mark. This can be met by photographing a monitor tube on which a signal of known frequency is displayed. A method described by Whipple(1) employs a mask over the tube screen. A series of slots is cut in the mask so that integral multiples of a single frequency may provide a range of time marks. An alternative method described by Rose(2) makes use of a thyratron as a light source for time marking. Recently, Robson(3) described a probe technique for making regularly spaced star images on the film.

For slowly moving films the time marks need to be sepa
by seconds rather than milliseconds or microseconds.
then better to use a time switch which operates a small
at regular intervals and marks the record accordingly.
same device may be used to work a pen for paper recor

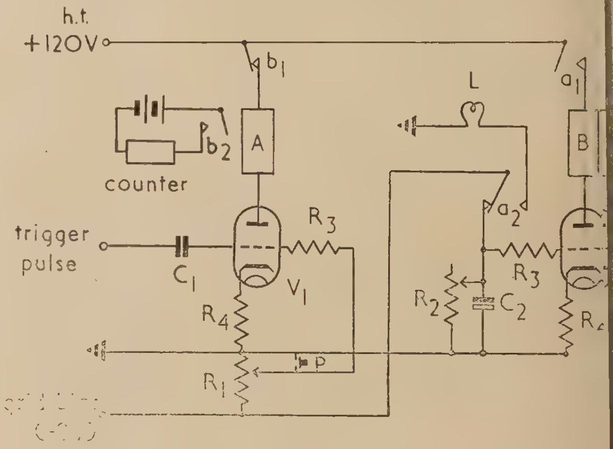
In recording traces a dual purpose unit capable of inde
and time marking is preferable. The unit to be desc
meets these requirements by having two modes of opera
First, relays operating the lamp and counter switches
energized at different instants, the time interval being
selected for adequate exposure. This mode may be initi
manually or by a positive triggering pulse obtained from
transient itself. The circuit then automatically resets
and cannot operate until a further pulse is received.
mode is used for indexing. Secondly, the relay sequence
be made repetitive, the time period being of the orde
seconds. This is the mode for time marking.

Two thyratron valves and two relays are connecte
shown in the figure. The properties of thyratrons are
known and their numerous applications in ion coun
circuits, trigger devices and time bases are to be found in
literature.(4)

The anode loads of the thyratrons V_1 and V_2 consis
electromagnetic relays *A* and *B*. These relays are energ
when the respective valves strike. The relay *A* has a
contact, a_1, and a make-and-break contact, a_2. The rel
has a break contact, b_1, and a make contact, b_2.

In the first mode of operation, the index lamp *L* is swit
on by the contact a_2 when *A* is energized, and the count
operated by b_2 when *B* is energized. In the second mod
operation, the counter is replaced by the time marking la
and operated by b_2. Alternatively, the thyratron V_2
may be used as a light source for marking.

The diagram shows the circuit in the off position for
first mode of operation. The bias control R_1 for



Circuit diagram of thyratron unit

R_1, R_2 = ½ MΩ potentiometer
R_3 = 10 kΩ
R_4 = 1 kΩ

C_1 = 0·1 μF
C_2 = 50 μF

V_1, V_2 = GTIC

Relay *A* operates contacts a_1 and a_2
Relay *B* operates contacts b_1 and b_2

thyratron V_1 may be set so that only incoming pulses
sufficient magnitude will cause V_1 to strike. Alternativ
V_1 may be made to strike by the momentary shorting of
bias control by the push button switch *P*. When V_1 stri
the energized relay *A* closes a_1 connecting the high tension
V_2, and switches the maximum bias voltage across the la
L through the make contact on a_2. The isolated conden

ischarges through R_2 until the bias voltage on V_2 reaches striking value when V_2 strikes. The time delay is detered by the setting of R_2.

he grid potential required to cause V_2 to strike is given by , where E is the h.t. potential and α is the control ratio of thyratron. The value of grid potential at a time t after C_2 ins to discharge is given by $v = v_0 \exp(-t/C_2R_2)$, where s the maximum bias potential. When v equals E/α, V_2 kes and the time delay, T, is therefore:

$$T = C_2R_2 \log_e (\alpha v_0/E)$$

he relation between T and R_2 is linear and the precision entiometer R_2 may be calibrated directly in seconds. For circuit values quoted, the maximum time delay is 19 s. s can be extended by increasing C_2 or R_2.

Vhen V_2 strikes the relay B closes b_2 and operates the nter. Simultaneously, b_1 is opened and V_1 extinguished. s switches off the index lamp and restores the maximum s on V_2. At the same time a_1 is opened and V_2 extinguished. s restores the high tension to V_1 and breaks the counter uit. The circuit is then ready for the next trigger pulse.

or the second mode of operation, the bias for V_1 is set a value above the striking potential. The sequence cribed above is followed until the closing of b_1 at the end ses V_1 to strike again. The operation is thus made etitive, the time interval being again dependent upon the ing of R_2. The time marking lamp is connected in place the counter and the index lamp is disconnected. This ures a momentary illumination each time V_2 strikes, and nimizes the drain on the bias battery. While intermittent eration does not seriously affect v_0, regular operation when e marking can result in a decrease in v_0 over long periods is left connected. This in turn will affect the time-mark cing.

REFERENCES

WHIPPLE, G. A. *J. Sci. Instrum.*, **13**, p. 291 (1936).
ROSE, D. C. *Canad. J. Res.*, **10**, p. 588 (1934).
ROBSON, R. C. *J. Sci. Instrum.*, **28**, p. 60 (1951).
WYNN-WILLIAMS, C. E. *Proc. Roy. Soc. A*, **132**, p. 295 (1931).

A method of preparing laminated copper

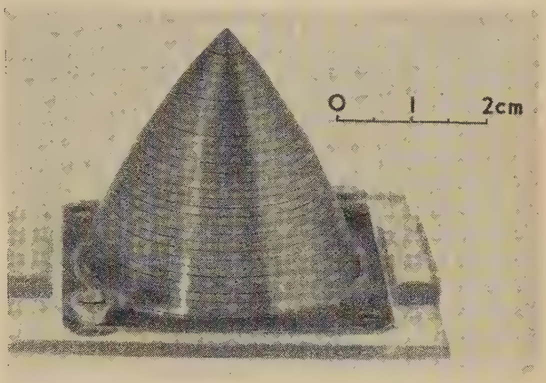
y K. NELSON, Betatron Research Group, Christie ospital and Holt Radium Institute, Withington, Manchester 20

[*Note received* 24 *May*, 1955]

ily machinable laminated copper was required to make ious shapes of X-ray filter for use in the strong a.c. field a 20 MeV betatron. The figure shows a finished sample one of these filters, the method of construction being as ows. Copper sheet $\frac{1}{32}$ in. thick was cut into sufficient ces, 2 in. square, and all the burrs removed by linishing. copper plates were then dipped individually into contrated nitric acid to remove oxide and scale, after which y were thoroughly washed in cold water to remove all ces of acid. Sufficient numbers of pieces of thin paper (in case 0·0015 in. thick) were cut to 2 in. square.

simple clamp jig was made to hold the copper plates en assembled for curing. Each copper plate was heated wiped over on both sides with a stick of Araldite type 1 nesive resin, leaving as thin a film as possible. The plates e built up on the jig with a piece of the paper between h piece. When sufficient were built up, the whole assembly h jig was heated to about 200° F, and when the adhesive was running freely the jig was clamped up tightly. The whole assembly was then cured at a temperature of 350° F for a period of $1\frac{1}{2}$ h.

On cooling, the copper block was milled and turned quite easily to the required shape, care being taken not to over-heat whilst machining. Care also had to be taken with finishing cuts since the copper burred over the interleaved paper and caused short circuits between plates. To obviate this difficulty the filter was polished, using 320s grade of emery cloth and then dipped again in concentrated nitric acid for two or three seconds, after which it was thoroughly washed in water and dried. The acid dipping had the effect of removing the fine burrs left over after polishing.



X-ray absorption filter for use in 20 MeV betatron

Samples made by this method have been subjected to some very rough treatment without harm. When measured with a 500 V megger, the resistances between plates were greater than 200 MΩ and the overall resistances were infinity. When subjected to strong 150 a.c. fields the blocks remained cool. The amount of copper per 1 in. of block was 0·84 in. Experimental blocks using Araldite and copper only were built up, but required more care in machining processes and were not quite so reliable in their insulation properties.

A simple relay-operated timer

By L. R. JENKIN, B.Sc., Physics Department, University of Exeter

[*Note received* 13 *June*, 1955]

The timing of experiments, such as particle counting in nuclear physics, is often performed by devices which depend on the frequency of the a.c. mains. Where a higher accuracy is required, relatively complex equipment is employed, such as a crystal-controlled oscillator or an electrically-maintained tuning fork, driving frequency-divider stages.

However, many buildings are fitted with clocks which are operated electrically by half-minute impulses from a master pendulum (e.g. the Gent's controlled clock system). These impulses have been found very satisfactory for timing. Their average error is within a few seconds a week, and the repeat accuracy is better than one part in 10^4.

The relay circuit used, Fig. 1, is arranged for one-shot operation and is reset by contact S_1. In our case this is on the "reset" key of the scaler used for counting. The "count" key of the scaler is of the Post Office pattern, and the "up" position, not otherwise used, is employed for the timer. Contacts, not shown, on this switch allow normal use of the scaler if required.

Before operation commences, switch S_1 must be momentarily closed to energize and lock-in relay $C/3$. Relay $A/2$ is energized by each clock impulse. Relay $B/3$ operates on the leading edge of the first clock pulse, $C/3$ releases on the trailing edge, and $B/3$ then releases on the leading edge of the second impulse.

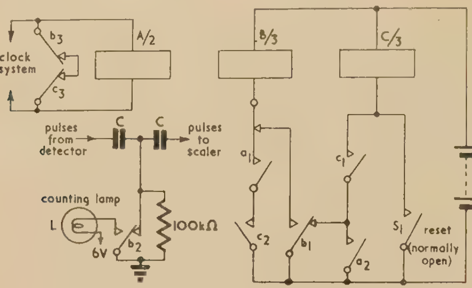


Fig. 1. Simple timer circuit. N.B.—In the "detached contact" method of circuit drawing, contacts a_1 and a_2 are those on the relay coil $A/2$. Contacts are shown in the position corresponding to no current in the relay coil. Note that a_1 is a make-before-break change-over contact. $C = 0{\cdot}001\ \mu F$

Since one impulse every half-minute amounts to over 10^6 impulses per year, contacts b_3 and c_3 were included to short-circuit relay $A/2$ when the timer is not in use. Using a 25 Ω relay for $A/2$, reliable operation was obtained without increasing the clock supply voltage. It should be noted that all the slave clocks, and the timer, are connected in series.

The timer was tested by counting 100 kc/s pulses from a crystal-controlled oscillator. About one hundred checks were made over a period of several days. Very little drift was observed but there were cyclic variations, due to the master clock, of ±2 ms (0·007% of 30s) having a period of 2 min. A 30% change in the current through $A/2$ or in the voltage applied to relays $B/3$ and $C/3$ resulted in less than 2 ms change in timing.

In order to time longer intervals the circuit shown in Fig. 2 may be used. A uniselector having coil US, contact us_1, and switch arms us_2 and us_3 is used. It is stepped forward at each half-minute impulse. Although any integral multiple of 30s may be obtained (limited only by the uniselector), the two most useful series, namely ½, 1, 2, 4, 8, 16, and ½, 1, 2, 5, 10, 20 min, are provided for.

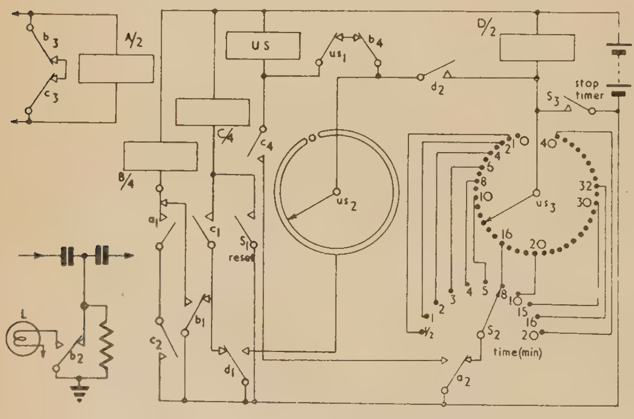


Fig. 2. Timer for longer intervals

In this circuit, relays $A/2$, $B/4$ and $C/4$ perform exactly as $A/2$, $B/3$ and $C/3$ before, except that $C/4$ is held on until contact d_1 opens. $D/2$ operates and locks in as soon path is completed through us_2 and S_2. $C/4$ then rele and at the next impulse $B/4$ releases, thereby terminatin interval and causing the uniselector to "home." This serves as a warning in addition to the lamp L. Push sw S_3 is indispensable when using the longer time interval it avoids waiting should a false start be made.

I wish to acknowledge the receipt of a grant from Department of Scientific and Industrial Research during time when this work was carried out.

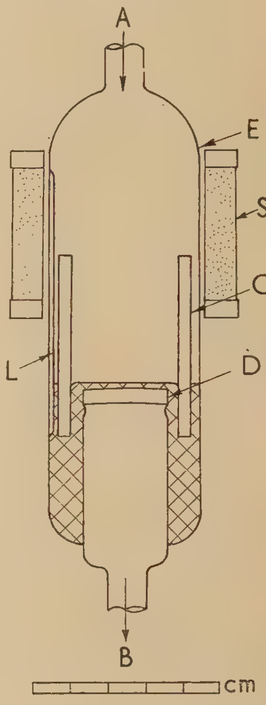
A magnetically operated vacuum valve

By R. M. Glaister, B.Sc., Grad.Inst.P., H. H. Wi
Physical Laboratory, University of Bristol

[*Note received* 21 *June*, 1955]

It is frequently desired to admit gas, from a reservoir a near atmospheric pressure, into an evacuated system. valve described allows of a relatively rapid, yet easily trollable gas flow, and entire freedom of contamination f vacuum grease.

The valve, shown diagrammatically in the figure, con of a slightly convex sintered glass disk D covered wit



Magnetically operated vacuum valve

A, gas admission side;
B, vacuum side;
C, iron cylinder;
D, sintered glass disk;
E, Hysil glass envelope;
S, solenoid;
L, re-entrant lines in envelope.

layer of mercury in which, in an outer annulus, a soft ir cylinder C floats. The glass envelope E of the valve surrounded by a 500 ampere-turn solenoid S allowing cylinder, of mass 50 g, to be lifted clear of the surface; t allows the 3·7 ml. of displaced mercury to run into annulus, leaving the dome clear.

The sintered glass disk was prepared by placing 80 m powdered Hysil glass to a depth of 5 mm in a graphite mou This was heated in an eddy-current heater until cohesi began to take place and the disk pressed to a thickness 3 mm. Care was taken while sealing this disk into the e of the tube B to avoid overheating, thus reducing the poro area. Three vertical re-entrant lines L made in the envelo ent a tendency for the cylinder to stick to the glass, ing operation sluggish. The iron cylinder was cleaned re assembly by eddy-current heating in a vacuum.

ie valve will withstand a pressure difference of at least atmosphere at A with respect to the vacuum side B, but verse pressure of only a few millimetres of mercury will e gas to bubble through the mercury layer.

ith a disk 2 cm in diameter the rate of flow was such the pressure of a 150 ml. reservoir, initially atmospheric, reduced to 1 cm in 45 s. Passage of gas with a pressure rence of less than 1 cm becomes increasingly slow.

ie gas transfer rate with this valve was found to be some orders of magnitude greater than that of a pair of ered glass disks brought into contact under mercury, h it superseded. The valve may be used in a partially i state by reducing the solenoid current, and thus the of disk not covered with mercury.

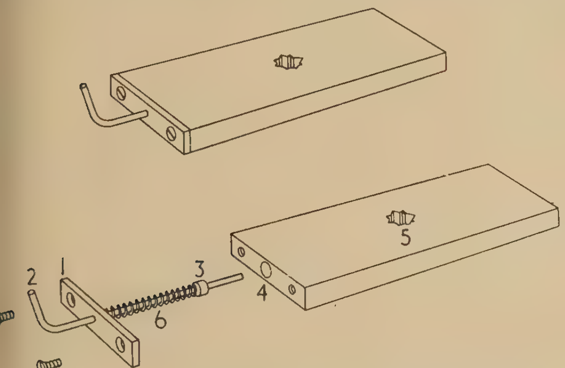
ie author acknowledges, with thanks, the assistance of J. Burrow in the construction of this valve.

An object holder for microscopic measurements

y H. Shapiro, Ph.D., Wills Hospital, Philadelphia, Pa., U.S.A.

[*Note received* 18 *August*, 1955]

facilitate the microscopic measurement of the bore or neter of small tubes, or the dimensions of certain other cts, the instrument shown in assembled and exploded vs in the figure has been constructed. This holder is a s plate, 78 by 25 mm, and 6 mm thick. Through the (1) a bent rod or handle (2) protrudes, which displaces spring-actuated plunger (3). The hole (4) extends from strip (1) through the plate to the centrally gouged hole (5)



Object holder in assembled and disassembled views

aining a V-shaped notch against which the other end of rod (2) is held by the spring (6). In use, the handle is ped to pull the rod away from the notch. The object to neasured is placed vertically in the notch, and the handle released, thereby engaging the object in the notch by ng tension. The holder is placed on the stage of the oscope. Its size allows it to be held conveniently in the hanical stage, if one is attached to the microscope, ipulated like a glass slide, and observed and measured er low or high power. For long objects, the condenser may be lowered, or swung aside, or removed, to allow object to project through the aperture of the microscope e. A filar ocular micrometer replaces the ocular; or, for precise measurement, an eyepiece micrometer disk may sed. Calibration of the filar or the disk is carried out as usual with a stage micrometer. Even if the tube is not accurately alined with the optical axis of the microscope, little error will accrue from small deviations from parallelism as the cosine of small angles (from 0° to 7°) ranges from 1·00 to 0·99.

The author is indebted to The American Philosophical Society for a grant from the Penrose Fund.

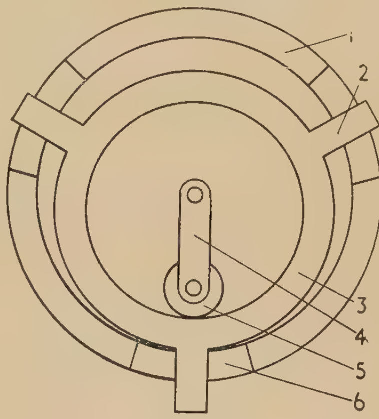
An adaptable mechanism for converting rotary motion into a succession of linear movements

By A. L. Sims, Physiology Institute, University of Wales, Cardiff

[*Note received* 11 *July*, 1955]

In this mechanism an arm (4) (see figure) provided with an end roller (5) is rotated horizontally by a suitable electric motor fixed to its under side. The length of the arm is such that the roller presses lightly against the inside of a metal ring (3), itself captive inside a metal cup (1). The outside diameter of the metal ring, which is less than the inside diameter of the cup, is provided with lugs (2), rectangular in section, which project horizontally through slots (6) in the wall of the cup. The slots in the cup are longer than the width of the lugs on the metal ring and the bases of the slots provide the bearing surfaces on which the lugs slide. Rotation of the motor spindle imparts to the loose metal ring, and thus to the projecting lugs, an irregular oscillating movement similar in form to that used in manual sifting. Modification of the lugs, or of the width of the slots, or of the diameter of the loose metal ring, can provide other useful movements as illustrated by the following.

Plan of
rotary
mechanism



(*a*) A shaker is made by screwing spring clips to the ends of the lugs, thus providing grips for conical flasks or other suitable glass-ware. With the provision of a plate for the top of the cup the whole mechanism, with motor attached, can be inverted and flasks can then be shaken in a water bath.

(*b*) Vertical pillars screwed to the upper surfaces of the lugs provide the foundation for a sifting device.

(*c*) Leaf contacts are mated successively by pressure from the ends of the lugs for rotary electrical switches.

(*d*) A loose metal ring without lugs, placed between the roller and a rubber tube inside the cup, provides an ideal rubber tube-pump in which the roller does not drag the tube.

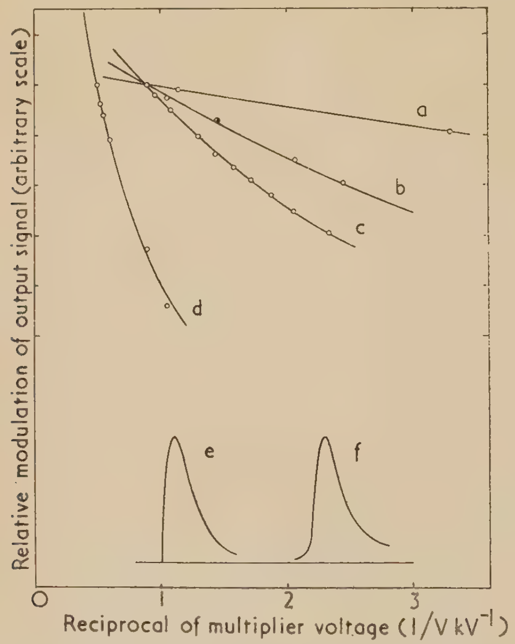
Other applications requiring the conversion of rotary to linear motion will be readily apparent.

Correspondence

Transit time spread in electron multipliers

When a photomultiplier tube is used to detect high-frequency signals the modulation of the multiplier output signal is reduced by the effects of electron transit time spread. Measurements have been made of this effect in the R.C.A. type 5819 (ten stages, focused) and the E.M.I. type 5311 (eleven stages, unfocused) photomultipliers and have been used to estimate the extent of transit time spread in these tubes.

The experimental data were obtained using an apparatus constructed for measuring photofluorescence decay times and which is to be described in detail elsewhere. Data obtained for signal frequencies of 12·9, 25·9 and 38·6 Mc/s are shown in the figure. This shows how the relative modulation of the output signal decreases as the overall operating voltage of the multiplier is reduced. This decrease occurs because transit time spread is greater at low operating voltages; providing that the velocity of ejection of secondary electrons is small, transit time spread is inversely proportional to the root operating voltage.



Relative modulation of multiplier output signal

Curves (*a*), (*b*) and (*c*) measured for the R.C.A. type 5819 photomultiplier. Curve (*a*) at 12·9 Mc/s, curve (*b*) at 25·9 Mc/s and curve (*c*) at 38·6 Mc/s. Curve (*d*) measured for the E.M.I. type 5311 photomultiplier at 25·9 Mc/s. The shape of the function $t \exp(-bt)$ is shown by curve (*e*) and the shape of the single electron pulse from the R.C.A. type C-7165A multiplier by curve (*f*).

To analyse these results the shape of the single electron pulse was approximated by the function $t \exp(-bt)$. The shape of this function is shown by curve (*e*) in the figure. It may be compared with curve (*f*) which shows the shape measured(1) for the R.C.A. type C-7165A multiplier, a typical focused design. The shape of the single electron pulse will vary for different types of multiplier structures but must necessarily be of the general form described by the present approximation. The parameter b was evaluated for each by normalizing the calculated curves at one point and a ing to find the value for best fit with the remaining p For the R.C.A. type 5819 photomultiplier the width a maximum of the single electron pulse was evaluated each of curves (*a*), (*b*) and (*c*) to be 5·9 mμs at an o operating voltage of 1·25 kV. This value compares factorily with that measured by Smith(2) using an oscillos technique. For the E.M.I. type 5311 photomultiplier th width was evaluated from curve (*d*) to be 20 mμs operating voltage of 2·00 kV.

The authors wish to thank the South African Counc Scientific and Industrial Research for a grant to pur equipment and for a maintenance grant to one (T. D. S. H.).

Rhodes University, T. D. S. HAMIL
South Africa. G. T. WRIGHT*

REFERENCES

(1) SWANK, R. K. *Nucleonics*, **12**, *No*. 3, p. 14 (1954).
(2) SMITH, R. V. *Phys. Rev.*, **98**, p. 1170 (1955).

* Now at Mullard Research Laboratories, Salfords, Surre

A capacitance-resistance hygrometer

Our paper published in the November issue of this *Jo* under the above title contains no reference to the ori observation(1) by Dr. F. Ansbacher to which our work its inception and to his suggestion to us that the effect be applied to hygrometry. The effect observed, which also reported in a subsequent joint publication Ansbacher,(2) is the variation with relative humidity o capacitance of a condenser containing anodised alumi oxide as dielectric material.

Although the priority of Ansbacher's discovery had already been established,(1, 2, 3) our inadvertent omissio suitable acknowledgement in the first full-length descri of the hygrometer to appear is sincerely regretted. We therefore to apologize for an omission that might we interpreted as a discourtesy and to state clearly tha development of the hygrometer stems from Ansbac original discovery.

Full acknowledgement to Dr. Ansbacher was made i earlier fuller paper on the hygrometer and the theory behaviour, which on editorial advice was split into papers. That dealing specially with theory contains acknowledgement.(4)

Torry Research Station, C. L. CUTTIN
Department of Scientific and A. C. JASON
Industrial Research,
Aberdeen.

Sir John Cass College, J. L. WOOD
London, E.C.3.

REFERENCES

(1) ANSBACHER, F. *Ph.D. Thesis*, University of Lo (1949).
(2) ANSBACHER, F., and JASON, A. C. *Nature* [*London*], p. 177 (1953).
(3) JASON, A. C., and ANSBACHER, F. British Patent 732969 (1955).
(4) JASON, A. C., and WOOD, J. L. *Proc. Phys.* [*London*] *B*, **68**, p. 1105 (1955).

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

otometer for assessing relative luminances of fluorescent powders. General Electric Co. Ltd., Magnet House, London, W.C.2.

photometer has been developed to measure the com- ative luminances of phosphors used in fluorescent tubes. repetition accuracy is claimed to be within 2%. The otometer consists essentially of a cubical box with a totally ck inner surface and a small circular hole in the centre of inged lid. Short wave ultra-violet radiation is provided a low pressure mercury vapour discharge in a quartz tube. is tube is bent into a circular shape round a photocell. e photocell is of the rectifier type and is covered by a filter ich gives it an approximate "average eye" response. The e and photocell unit are mounted in the base of the box h their centres vertically below the lid aperture. A ndard circular glass box or "cell" has been designed which lds about 5 g of the phosphor. When the lid of the cell screwed down, the powder is compressed into a layer 2 mm thick and a uniform and a repeatable surface is tained on the transparent window in the base of the cell. r rapid comparison of luminances two such cells are used, th having crystal quartz windows. One cell is filled with powder under test and the other with a standard material. A small quantity of visible light is also emitted by the ra-violet lamp and reflected from the surface of the osphor. This amounts to about 30% of the total radiation ling on the photocell. To allow for this visible light in essing the relative luminances of the phosphors a third l, also containing the standard phosphor but having a ndow made of glass, is introduced. The glass prevents ra-violet radiation reaching the phosphor so that only lected visible radiation from an ultra-violet lamp reaches photocell. This component can then be subtracted from figures previously obtained, thus giving the required io of sample to standard fluorescence.

ase-sensitive voltmeters. Solartron Electronic Group Ltd., Solartron Works, Thames Ditton, Surrey.

e type VP250 voltmeter indicates simultaneously on two n. centre-zero meters the in-phase and quadrature com- nents of an applied test voltage with respect to a given erence voltage. The reference and signal inputs are fed ough channels of wide-band amplification to opposite gonals of a Wheatstone bridge with equal arms. Adjacent ns of this consist of thermojunctions, the outputs of which connected in series opposition to a d.c. voltmeter. The ding of this is then proportional to the product of the erence voltage and the in-phase component of the signal tage. A similar unit with a phase shifting unit in the erence channel enables the quadrature component of the nal to be read on a second meter. Provided the reference tage is of sine wave form, the indicated values are un- ected by harmonics or spurious frequencies in the test nal. The amplifiers are designed to run into cut-off under erload conditions and thus protect the thermojunctions. e instrument has seven ranges from 15 mV to 15 V with input impedance of over 50 MΩ. The accuracy claimed bout 2% over the frequency range 20 c/s to 20 kc/s.

The instrument described above is intended for measuring the transmission characteristics of amplifiers, networks and high-speed servo-systems. For the study of low-speed servos, the type VP253 voltmeter may be used. This is a development of the type VP250 meter and covers the voltage range 50 mV to 150 mV in eight ranges at frequencies from 0·01 c/s to 11·1 kc/s. There is also a two-phase amplitude-stabilized oscillator covering the same frequency range for use with this instrument.

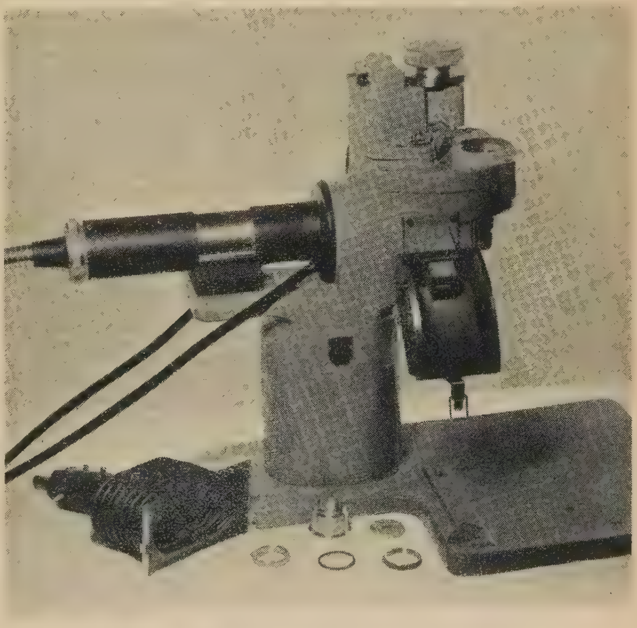
Microswitch. Burgess Products Co. Ltd., Dukes Way, Team Valley, Gateshead, 11.

A microswitch, type V4, is available having approximate overall dimensions of $\frac{3}{4} \times \frac{1}{2} \times \frac{1}{4}$ in. It is robustly constructed and housed in Bakelite; it will make and break 5 A at 250 V (a.c.) or 2 A at 30 V (d.c.) and it has a probable life of 50000 operations. It is a single-pole changeover switch with a positive snap action. Minimum contact separation is 0·010 in.

The switch is operated by depressing a small Bakelite plunger; the maximum force required is 7 oz. For applications where it is not possible to apply the operating force at 90° to the alinement of the switch or when the actuating medium is a cam or sliding dog, auxiliary actuators with either plain levers (ref. V4L1) or roller levers (ref. V4LR1) are available.

Attachment for X-ray fluorescence analysis. Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

In this Norelco "three-specimen inverted spectrograph" the X-ray beam strikes specimens from below and excites the characteristic radiations, the spectra of which are measured by a Geiger counter, proportional scintillation detector or



Three-specimen, inverted spectrograph

similar device. It is suitable for the analysis of metals, powders and liquids such as heavy waxes and oils. The instrument has three specimen holders measuring $1\frac{3}{8}$ in. diameter by $1\frac{3}{8}$ in. deep which fit into a horizontal disk that rotates inside a leaded-bronze rayproof housing. The disk shaft extends through the top of the housing and has a knob which the operator turns manually when he wishes to change specimen positions. An indexing device centres each specimen when over the beam.

Specimen holders have mylar windows held in place with retaining rings to facilitate replacement. A nickel foil collimator with $\frac{1}{8}$ in. spacing is built into the instrument. Pedestal height and base are designed to accommodate the standard Norelco wide-range goniometer. The instrument can be used with the X-ray tube which is standard on Norelco spectrograph installations, but in this case the window faces upward. Special accessories are available.

Multirange test meter using transistor amplifier. British Physical Laboratories Ltd., Houseboat Works, Radlett, Herts.

The d.c. test meter marketed under the name "Transranger" has a resistance of 1 MΩ/V. It is equipped with a d.c. transistor amplifier comparable to a conventional valve voltmeter. As the transistors require a standing current of approximately 350 μA, they are supplied from an internal $4\frac{1}{2}$ V battery. An on-off switch is not required as the small current drain does not affect the life of the battery. The instrument is therefore always ready for operation, no warming-up time being required. In order to correct for the effect of temperature on the transistors, an internal standardizing voltage is provided which can be connected to the amplifier through a spring-loaded key switch. Should the gain of the amplifier have changed, it can be readjusted by a control knob. It is stated that this is seldom necessary as the transistors are mounted in a thermally insulated container. An unusual feature is the provision of a control which enables the pointer to be set at half scale, thus converting the instrument into a centre zero voltmeter or galvanometer. Indication is by a 5 in. scale meter fitted with knife-edge pointer and mirror scale. An accuracy of 3% of full-scale deflexion is claimed on all ranges. The instrument has the following ranges:

Voltage 0–100, 300 mV, 1, 3, 10, 30, 100, 300, 500 V.
Current 0–1 μA.
Resistance 0–1, 10, 100 MΩ.

Wide-band, two-channel oscilloscope. Nagard Ltd., 18 Avenue Road, Belmont, Surrey.

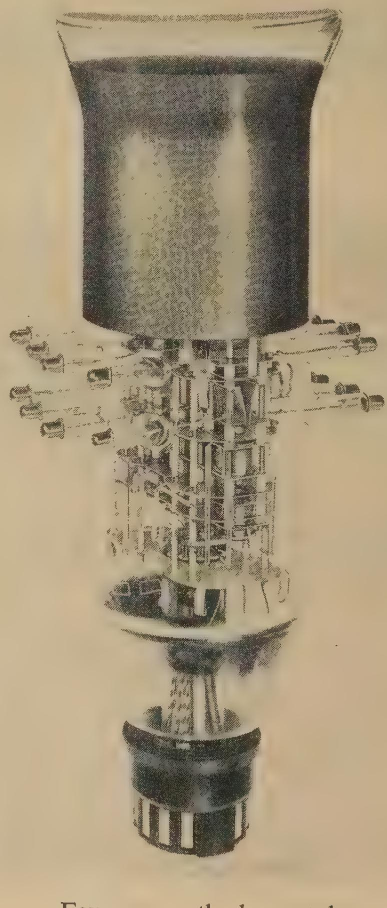
The chief feature claimed for the model DE 103 oscilloscope is that it includes two identical but independent wide-band, d.c. amplifiers in the somewhat confined space of an oscilloscope case of reasonable size. The two identical Y-amplifiers, which are calibrated for voltage measurement, provide similar signal handling conditions as to phase shift, response and gain, giving confidence that the two displays are truly comparable. The 6-in. diameter flat-screen, cathode-ray tube has separate gun systems screened against interaction effects at the highest frequencies at which the instrument can be used. The tube can be supplied with either a blue or green trace, and is corrected for pin-cushion distortion. A useful feature is a ruled graticule with controllable illumination, which enables calibrated oscillograms to be produced. Access is provided for direct connexion to the deflexion plates and control grids.

The time base of the instrument provides continuo variable sweep times from 0·2 s to 2 μs per 10 cm on channel. The calibrated sweeps provide a basis for measurements by a speed control dial calibrated direct microseconds, and giving an average accuracy better than The triggering gives full screen sweeps from either nega or positive pulses of 50 mV at repetition rates up to 250 Continuously repeating sweeps are also available which synchronized from signals down to less than 10 mV. I vidual X-shift controls on the two beams enable the tr to be alined in any desired manner. An X-amplifier wi three-step attenuator can be switched in to provide a resp from zero to 500 kc/s with a maximum gain of 100.

The two identical Y-amplifiers each have an input impeda of 1 MΩ and 20 pF. Attenuator steps of 1, 3, 10, 30, and 300 are provided. The rise time is given as 0·03 without overshooting and the frequency range is from to 6 Mc/s (−1 db) or 10 Mc/s (−3 db). The maxi sensitivity is 0·25 V/cm. An accuracy of 5% is claime the voltage calibration.

Four-gun cathode-ray tube. 20th Century Electronics L King Henry's Drive, New Addington, Surrey.

The Q6 series of tubes, illustrated in the figure, employ independent electron guns. All sixteen deflector plates separately connected to side arms, and interplate screen ensures absence of intermodulation. The traces can superposed, and each gun has a useful scan area of at l 100 × 70 mm. Independent connexions to the four g



Four-gun, cathode-ray tube

focus electrodes permit optimum operation for each , and separate brightness modulation of each beam. The e is available with blue, green, medium persistence, long istence and fluoride screens. The blue screen is capable ecording sweep speeds up to 100 cm/μs.

and spark stands and source units. Hilger and Watts Ltd., Hilger Division, 98 St. Pancras Way, London, N.W.1.

Hilger routine arc and spark stand allows electrodes to inserted in correct alinement and provides adequate ening to prevent interference. The makers claim that r initial setting its alinement is maintained for long periods. stand can also be used for pencil electrodes or flat ples. The gap width and position is variable and is rately reproducible. A changeover switch may be fitted ch allows the polarity of the electrodes to be reversed.

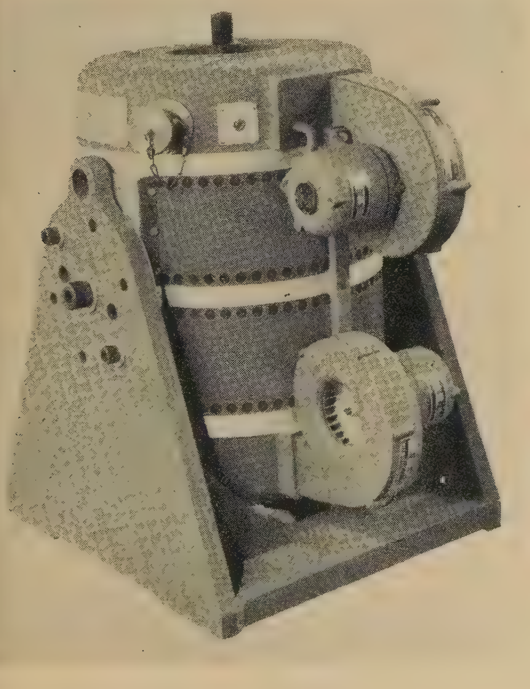
he stand is also available with the lower electrode holder aced by a rotatable spindle. This spindle carries a phite wheel which dips into a boat containing the liquid g examined. The polarity switch is not included, and in place is fitted a small, single-speed motor drive for the phite wheel.

ration generator. Goodmans Industries Ltd., Axiom Works, Wembley, Middlesex.

e largest model of vibration generator in the range manutured by this firm is known as the model 16/600. It is of l armature design with a peak force of 500 lb. The ural frequency is 20 c/s and its range is up to 1000 c/s. e generator has a thrust force factor of 27 lb/A with a ximum continuous current rating of 13 A and the total ursion of the stroke is 1 in.

he dual armature system consists of a number of coils of t resisting enamelled copper wire wound on two light alloy mers which are slotted to minimize eddy current damping. ies/parallel connexions of the coils are afforded by terminal links. The laminated Bakelized suspension spiders are attached at either end of the driving shaft by six socket screws and are clamped at four places on their outer edges.

Attached to the main assembly body are two air blowers which allow the specified current ratings to be applied. The body has a trunnion mounting enabling it to be used at four driving angles at 30° intervals. The total weight of the assembly is about 6½ cwt. A suitable power oscillator is also available.



Vibration generator

E.H.T. power unit. Ericsson Telephones Ltd., Instrument Division, Beeston, Nottingham.

The power unit type 105 provides an e.h.t. supply for most types of radiation detector as well as supplies for a probe unit. The e.h.t. supplies are continuously variable from 300 to 3300 V in three ranges. Maximum current on the 300–1200 V and 1000–2000 V ranges is 2 mA and on the 1800–3300 V range it is 0·5 mA. The output voltage is indicated on a 4-in. moving coil meter. The maximum ripple is 20 mV peak to peak, and much less than this for small current outputs. A shunt-type stabilizer employing a high-gain amplifier gives a stability ratio greater than 100 : 1 for mains changes between -10% and $+5\%$ of normal. The stabilized supplies available for a probe unit are 10 mA at $+300$ V, 7 mA at -150 V, and 1·5 mA at -100 V. There is also an unstabilized a.c. supply of 2·5 A at 6·3 V.

Oscilloscopes. Southern Instruments Ltd., Frimley Road, Camberley, Surrey.

Two new general purpose oscilloscopes have been developed incorporating flat screen 6 in. cathode-ray tubes by 20th Century Electronics Ltd. The M972 oscilloscope uses a dual-gun tube and the type M974 a four-gun tube. The gun assemblies are entirely separate, enabling full use to be made of independent beam and plate controls without interaction. Separate identical Y-amplifiers for each beam make possible the direct comparison of waveforms. The gain of each Y-amplifier is continuously variable from 80–1500 over a frequency range from zero to 100 kc/s. Resistance-capacity coupling can be provided by switch selection, and there is a frequency compensated 10 : 1 input attenuator. The time base is continuously variable from 2 c/s to 30 kc/s, and can be synchronized internally or from an external signal of 100 mV or more. In addition, provision is made for synchronization from contacts on a machine or vibrator, and for beam triggering from the timing contacts of a camera. Time marking by brightening or blanking pulses may be applied by Z-axis modulation.

Cellophane sealing iron. The Acru Electric Tool Manufacturing Co. Ltd., Chapel Street, Stockport Road, Levenshulme, Manchester, 19.

An iron is available which seals Cellophane and plastics such as polythene by a simple rolling action over two sheets of the material; only slight pressure is needed. The iron takes 2 min to reach a working temperature and its rating is 45 W. The iron can be supplied for all voltages with either a Bakelite or wooden handle and the copper bit and the wheel it supports are chromium plated. Three different wheels for various purposes are included with each iron.

There is also a knife-edge sealing iron which is more suitable for heavier gauges of plastic sheets, but can also be applied to the lighter gauges if required. Heavier pressure can be applied with the knife-edge iron than with the roller type.

Notes and comments

Competition of craftsmanship and draughtsmanship

The Physical Society will again hold its annual craftsmanship and draughtsmanship competition for apprentices and learners in 1956. All the competitors must be under 22 years of age on 31 March, 1956. The classes under which work may be submitted are: (i) scientific instruments and components; (ii) tools and gauges; (iii) optical components and systems; (iv) blown-glass and silica ware; (v) sections of instruments, functional scale models of scientific interest and patterns; (vi) draughtsmanship.

The entries submitted will be displayed at The Physical Society's annual exhibition of scientific instruments and apparatus which will be held from 14 to 17 May, 1956, and a selection of the prizewinning entries may be transferred to The Science Museum for a short period following the exhibition. Further details may be obtained from The Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7.

Exhibition of supervoltage machines for X-ray therapy

The Science Museum has completed a small group of exhibits, relating to linear electron-accelerators, in the Atomic Physics Collection. They include sectioned parts of an actual accelerator, presented by Mullard Ltd., a most ingenious mechanical model illustrating the principle of the travelling-wave accelerator, lent by the Metropolitan-Vickers Electrical Co. Ltd., several diagrams showing the construction and operation of these accelerators, and a group of photographs showing them in use in Hammersmith Hospital and in the Megavolt Treatment Unit at Newcastle upon Tyne.

Other exhibits in this field also placed on view in The Science Museum are a betatron presented by the Clarendon Laboratory, Oxford, a model of the Philips cascade generator at the Cavendish Laboratory, Cambridge, and a mechanical model illustrating its principle lent by the Westinghouse Brake and Signal Co.

Catalogue of British electrical products

The third edition (1955–56) of the BEAMA catalogue classifies the electrical equipment manufactured by firms which are members of the British Electrical and Allied Manufacturers' Association (Inc.) into three sections: (i) electrical power plant, (ii) electrical equipment in industry, transport and communications, (iii) domestic and commercial electrical appliances, lighting, accessories and installation material. Other sections are a buyers' guide, a trade directory, an index to the catalogue and a glossary in five languages: English, French, German, Portuguese and Spanish.

Further details may be obtained from: The British Electrical and Allied Manufacturers' Association, 36–38 Kingsway, London, W.C.2.

Soviet Physics

The American Institute of Physics announces the pub
tion of a new bi-monthly journal entitled *Soviet Phy*
This publication will report, in English, current S
research in physics as contained in the *Journal of Ex*
mental and Theoretical Physics of the Academy of Scienc
the U.S.S.R.

One volume is published annually. Volume 1 (1955)
contain three issues and subsequent volumes, beginnin
January 1956 will contain six issues. The subscription
are: Vol. 1 (1955), $16.00; Vol. 2 (1956), $32.00. (In U.
and Canada these subscriptions are $15.00 and $30.00.)

Subscriptions should be addressed to the American Inst
of Physics, 57 East 55th Street, New York 22, New Yor

Journal of Scientific Instruments

Original contributions accepted for publication in future is of this Journal

An X-ray absorptiometer for the determination of tetraethyl lead in petrol J. F. Brown and R. J. Weir.
An instrument for measuring respiratory rates and volumes. By W. Nisbet
An attachment for high-temperature single-crystal X-ray work. By L. S. and H. F. W. Taylor.
A magnetic spectrometer. By D. J. Prowse and W. M. Gibson.
A water vapour recorder for equatorial use. By C. G. Webb and A. Rajara
A continuous-flow rotational viscometer for use with downward- suspensions. By G. F. Eveson and E. W. Hall.
A constant volume membrane interferometric microrespirometer. By E Turner.
A logarithmic megohmmeter. By P. Hariharan and M. S. Bhalla.
An automatic scanner for nuclear emulsion. By S. J. Goldsack and H. B. a Raay.
An improved helium liquefier and cryostat. By D. F. Brewer and D. O. Edw
A cell for kinetic measurements of gas evolution from systems irradia fast electron beams. By C. B. Amphlett and T. F. Williams.
A precision high temperature specimen chamber for an X-ray diffracto By G. K. Williamson and A. Moore.
The temperature calibration of a high temperature X-ray diffraction ca By J. A. Brand and H. J. Goldschmidt.
Devices for automatic potentiometric titration. By R. Audran and D. T Dighton.
A calorimeter for measuring energy absorption from pile radiation. By A Anderson and R. J. Waite.
An analysis of injection phenomena in the Birmingham proton synchro By C. A. Ramm, R. F. Coe and T. B. Vaughan.

British Journal of Applied Physics

Contents of the January issue

CONFERENCE REPORT

Summarized proceedings of a conference on stress analysis—Sheffield, Septem 1955. By H. Spooner.

ORIGINAL CONTRIBUTIONS

Specimen thickness and image resolution in electron microscopy. By V Cosslett.
The analysis of gases at low pressures. By M. A. Cayless.
A study of the Formvar replica process. By A. W. Agar and R. S. M. Reve
Caesium 137 for industrial radiography. By R. S. Morgan.
The automatic recording of electron diffraction patterns applied to the stu evaporated copper layers. By R. B. Kehoe, R. C. Newman and D. Pashley.
Electrode deterioration in "keep-alive" discharges in transmit-receive swit By D. Walsh, A. W. Bright and T. J. Bridges.
A microwave resonant cavity method for measuring the resistivity of s conducting materials. By J. G. Linhart, I. M. Templeton and R. Dunsm
The corona resisting property of polytetrafluorethylene. By K. Sugita, S. N and Y. Toriyama.

NOTES AND NEWS

New books Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 10*s*. each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

The temperature calibration of a high temperature X-ray diffraction camera*

By J. A. Brand, B.Sc., and H. J. Goldschmidt, D.Sc., F.Inst.P., The B.S.A. Group Research Centre,
Greystones Hall, Sheffield

[*Paper received* 12 *October*, 1955]

The accurate measurement, by a thermocouple, of the temperature of fibre specimens in an X-ray high-temperature camera, of the type containing a spherical furnace enclosure, is investigated. Factors affecting the calibration of the thermocouple are discussed, and it is shown experimentally that the chief cause of discrepancies is the abstraction of heat along the thermocouple wires. Methods for calibrating the thermocouple in position, and for reducing the correction required to a minimum, are presented.

previous paper(1) a high temperature X-ray diffraction era was described, sponsored by the then powder camera el of the X-ray Analysis Group of The Institute of Physics developed at the B.S.A. Group Research Centre. A nd improved version of this instrument has since been t,(2) which has served as a basis for the development, in lified form, of a new commercial camera by Unicam Ltd. his second model has been in regular use in many arches, and experience with it has re-emphasized a number basic problems. One of the most important is that of urate measurement of the powder specimen temperature, the object of this paper is to discuss the difficulties lved from the user's viewpoint and to suggest methods overcoming them.

he problem of precise temperature measurement of the der sample is a fundamental one in any instrument in ch an internal standard is not used and the means of surement (thermocouple) cannot be in direct contact the specimen. The difficulty has been investigated, for ance, by Berry, Henry and Raynor.(3) In the present era an endeavour has been made to produce, as near as sible, a uniform temperature enclosure, by means of two osing hemispherical furnace halves. The general layout ndicated in Fig. 1. Conditions inevitably defeating the l are, of course, the X-ray gap and the specimen and mocouple entries.

has been shown by axial exploration across the furnace with the thermocouple that the temperature is constant hin a few degrees, and that the constancy improves as the perature is raised. However, under certain conditions a considerable discrepancy becomes apparent between the temperature indicated by the thermocouple and that of the specimen, as deduced from lattice spacings of pure metals and known dilatometric data.

It was decided to investigate this effect more closely and to provide an accurate means of calibration, based on the lattice expansion of pure substances. The results are reported here, as they were thought to be of general interest to users of any instrument of similar design.

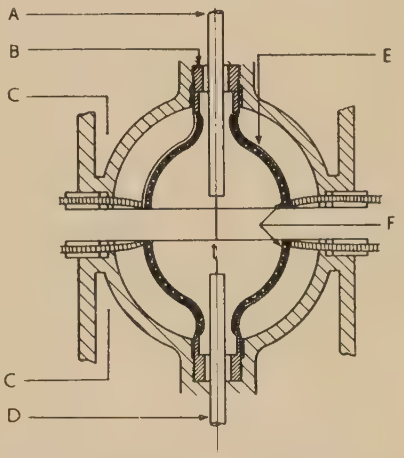


Fig. 1. Schematic layout of furnace

A, specimen mount (alumina); *B*, steatite bush; *C*, cooling water; *D*, thermocouple support; *E*, furnace shell (0·010 in. platinum foil); *F*, furnace winding [0·026 in. Pt/Rh (87/13) embedded in alumina].

It should be emphasized that the present problem only refers to the powder type of specimen, whilst in the case of block specimens, for which the camera is also adapted, the difficulty does not apply, as the thermocouple can be in contact with the sample. Also, the work was carried out under radiative conditions (vacuum), whereas under convective conditions (gas atmosphere) the correction necessary would be considerably modified, and, in fact, less.

CHOICE OF MATERIAL

The choice of material for calibration was governed by the following desiderata (apart from crystallographic

---

ote added in proof. On completion of the present k, an investigation by Pease (private communication) e to our notice, since published,(17) in which the problem pecimen temperature measurement was discussed from theoretical and experimental viewpoint for conditions lying to the earlier type of Unicam high-temperature era, in which the furnace geometry was considerably more ricted. It was gratifying to find that, in so far as the ditions are comparable, the general conclusions are very lar.

The substance of this paper was presented, amongst other -temperature camera topics, in a short paper at the Spring ference of the X-ray Analysis Group of The Institute of ics, Bristol, 1955.

conditions, e.g. suitable high angle reflexions for the given wavelength).

(i) Accurate information on the thermal expansion coefficient should be available, preferably based on precision dilatometric methods, since these are generally more accurate than X-ray data.
(ii) The coefficient of thermal expansion should be large, for maximum sensitivity.
(iii) The melting point of the material should be high in order to obtain as wide a range of temperature as possible.
(iv) A high-purity material should be used, and one for which the risk of contamination (e.g. oxidation, carburization) could be excluded.

A metal is generally preferred to a ceramic oxide (e.g. magnesium oxide, silicon dioxide) and silver, platinum and tungsten, amongst other metals, each have some favourable characteristics, though none is ideal.

Silver has a high coefficient of expansion ($19 \cdot 5 \times 10^{-6}$ per °C) which has been the subject of a number of investigations, both by X-ray and dilatometric methods, and reliable data are known. However, its low melting point (961° C) limits its use, whilst platinum and tungsten with their high melting points have lower coefficients of expansion.

Iron was an attractive possibility, because it would (in the writer's applications) serve as a basic standard for later steel investigations, and the A_3-change would provide additional data, but owing to wide disagreement amongst known dilatometric data and a considerable α/γ hysteresis effect, this metal was considered more suitable as an object of, rather than as a basis for, investigation.

(It may be mentioned that the iron expansion has actually been investigated by the writers, to be reported separately, and found to be in satisfactory agreement with the recent work of Basinski, Hume-Rothery and Sutton.(4))

Accordingly it was decided for the present to use silver for calibration up to approximately 900° C, and platinum and tungsten for higher temperatures. All wire specimens were annealed previous to the exposures, to relieve any cold work, a precaution always advised.

CALIBRATION DATA

Silver. Two sets of data on the coefficient of expansion of silver were referred to: one by Hume-Rothery and Reynolds(5) obtained by X-ray methods and related to Scheel's older dilatometric figures(6) (also used by Jay(7)), the other by Esser and Eusterbrook(8) based on dilatometric measurements. There was good agreement between the two sets of results (except for slight divergencies above about 700° C), and the curve of Esser and Eusterbrook was later chosen as the basis.

X-ray high-temperature photographs were taken of the silver (wire) specimen, at a series of temperatures up to 900° C, using CoKα radiation. The lattice parameters of silver were obtained with an accuracy of about $\pm 0 \cdot 0002$ kX, the random error in temperature measurement being less than 2° C. The spacing-temperature plot obtained was compared with that calculated from the dilatometric results. This is shown in Fig. 2, giving the deviation ΔT of the observed from correct temperature. ΔT varies from zero at 0° C, to a maximum of about 40° C near 400° C, thereafter falling steadily to about 5° C at 900° C.

Tungsten. With the tungsten-wire a spacing-temperature characteristic in relation to standard values was again plotted (Fig. 2); dilatometric work by Worthing,(9) confirmed by Hidnert and Sweeney, was here used as the basis. A the maximum value of ΔT was at about 400° C.

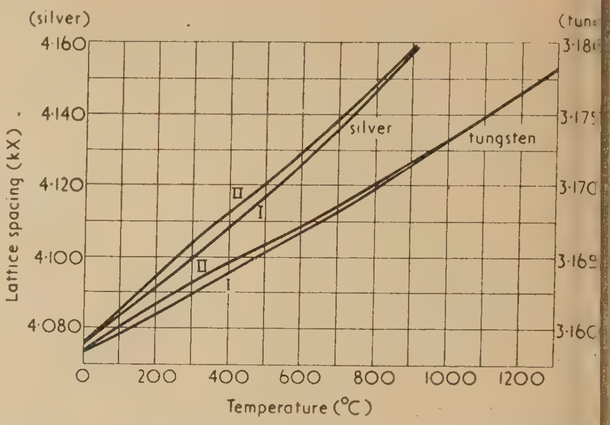


Fig. 2. Temperature calibration of high-temperatu X-ray camera using silver and tungsten. Thermocoup diameter, 0·013 in.

I = dilatometric (Esser and Eusterbrook for silver; Worthi for tungsten).
II = as measured.

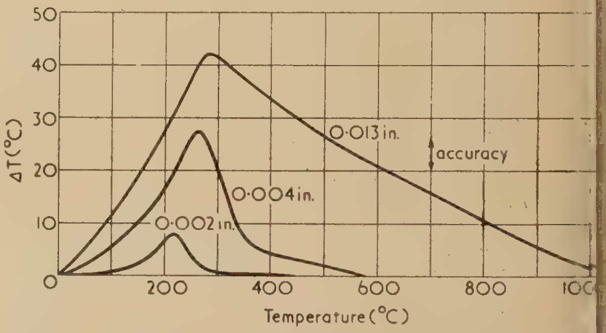


Fig. 3. Temperature calibration in high-temperatu X-ray camera; for fibre samples

Deviation ΔT as a function of temperature for varying thickne of thermocouple wire.

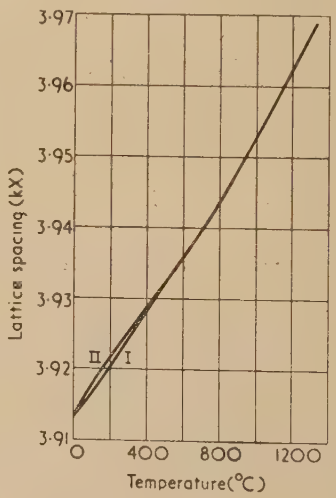


Fig. 4. Thermal expansion of platinum wire

I = dilatometric (Esser and Eusterbrook).
II = as measured in X-ray high-temperature camera.
(Thermocouple wires 0·004 in. diameter.)

By combining the silver and the tungsten calibration, a rection graph was obtained (see Fig. 3) which could be d to find the correction to be added to the observed nperature for other specimens under similar conditions.

Platinum. For the calibration using platinum as standard, dilatometric results of Esser and Eusterbrook(8) were d as basis; the resulting correction curve agrees, within experimental accuracy, with that for silver and tungsten. ticipating later results with 0·004 in. thick thermocouple re, Fig. 4 shows a calibration curve obtained with platinum. This metal is, no doubt, particularly important in high-nperature work, in view of its useful double role of specimen rier and internal calibrant, but difficulty may be experienced rough undue crystal growth.

CAUSE OF DEVIATION

The principal factors which might affect the temperature libration are:

(i) difference in emissivity between specimen and thermocouple;
(ii) selective loss of platinum or rhodium from the platinum–rhodium leg of the thermocouple through vaporization;
(iii) diffusion of rhodium into the platinum leg of the thermocouple;
(iv) contamination of the thermocouple by material from the specimen;
(v) conduction of heat along the thermocouple wire.

(i) Berry, Henry and Raynor(3) have pointed out that if ere is a gap in a furnace, so that black-body conditions are ly approximate, then the temperature attained by the ecimen will depend upon its absorptive power.

However, blackening tests, carried out at an experimental mperature of 500° C in the present camera, showed this fect to be negligible; but it is suggested, in cases of specimens here difference in emissivity may be important, to apply tificial "blackening" by means, for instance, of a suitable ramic oxide coating.

(ii) As rhodium has a higher vapour pressure than atinum (in spite of its higher melting point), there is the nger than a gradual composition-change might occur in a cuum at a very high temperature. X-ray examination of a ecimen of thermocouple wire after prolonged use in the mera, showed no significant composition change as termined by change of spacing between hot and cold rtion of the platinum–rhodium wire.* The temperatures re had, however, not exceeded 1300° C, while the effect ould probably only become appreciable from about 1400° C wards.

(iii) Diffusion of rhodium into the platinum leg of the ermocouple is another possible cause of trouble, since a ry small amount of rhodium appreciably alters the thermoectric characteristic of pure platinum. The effect is to ove the effective junction from the weld down the platinum re, but this is not important under conditions where the mperature gradient of the furnace near the bead of the ermocouple is small, as it is in the present case.

With reference to factors (ii) and (iii), it may be mentioned at, in order to minimize any possible effects of this nature, have replaced the 0% rhodium/13% rhodium by a 1% rhodium/13% rhodium couple, in which case the influence upon thermal electromotive force of a slight secondary change in rhodium content can be much reduced.(11)

(iv) The effect on the thermocouple of vaporization of the specimen is difficult to estimate and obviously depends on the type of sample. However, as the thermocouple and the specimen are at approximately the same temperature, there should not be any heavy deposition. If the vapour pressure of a given specimen metal or alloy element in vacuum at the given temperature is excessive, precautions must in any case be taken, such as the use of a protective coating or a gaseous atmosphere.

Any deviation due to the above four effects would increase steadily with temperature, and to a certain extent could readily be checked by periodic re-calibrations, except for the emissivity variable depending on specimen condition.

(v) The effect of conduction of heat along the wire away from the thermocouple junction is to destroy the black-body conditions at the point, namely, the thermocouple re-radiates less heat than it receives. This can be put on an approximate quantitative basis:

Let T_1 be the absolute temperature of the specimen, T that of the thermocouple and T_0 room temperature. Then the heat received per second by the thermocouple is given by

$$A\sigma e T_1^4$$

where A is the area of the thermocouple receiving energy, σ is Stefan's constant and e is the emissivity of the surface. Similarly, energy re-radiated equals

$$A\sigma e T^4$$

and heat conducted away along thermocouple wire equals

$$(Ka/L)(T - T_0)$$

where K is a constant, depending on the coefficients of thermal conduction of the thermocouple metals, a is the cross-sectional area, and L the effective length of thermocouple.

Thus $T_1^4 - T^4 = C(T - T_0)$ where $C = Ka/LA\sigma e$.

If we now put $\Delta T = T_1 - T$, we get

$$4T^3\Delta T + 6T^2\Delta T^2 + \ldots = C(T - T_0)$$

or ignoring terms containing higher powers of ΔT

$$\Delta T = [C(T - T_0)]/4T^3$$

This idealized expression for ΔT tends to zero at high values of T, and has a maximum value independent of C (which, in this case, works out at $T = 400°$ K).

This expression thus accounts, at any rate in principle, for the main features of the curve of ΔT against T in a way that the other possible mechanisms do not.

It is concluded that the cause of the large corrections required to the measured temperatures is essentially loss of heat along the wire of the thermocouple. In order to minimize the effect, the constant C in the expression for ΔT must be kept as small as possible.

REDUCTION OF THE TEMPERATURE CORRECTION

One way of reducing $C = Ka/LA\sigma e$ would be by increasing the diameter of the weld of the thermocouple and thus the surface area A receiving radiation. This process is limited by the maximum size of weld that it is, in practice, possible to produce, as well as by the maximum bead-weight that can be carried by the thermocouple wire at temperature without sagging.

---

* It is a convenient method to check the platinum/rhodium ratio thermocouple wires, before and after use, by means of the lattice nstant change on X-ray analysis.(10)

However, by reducing the diameter of the thermocouple wire, a more advantageous a/A ratio may be obtained. The results of successive calibrations with wires of 0·013, 0·004 and 0·002 in. diameters are shown in Fig. 3. Beads of 1 mm diameter were easily produced. The decrease in the value of ΔT with diameter at any given temperature is striking; so also is the fact that the maximum value of ΔT occurs at roughly the same temperature in each case, as predicted by theory. It seemed that the correction could, for practical purposes, be reduced to zero by using wires of 0·002 in. diameter. However, the 13% rhodium wire is difficult to draw to this dimension, and the frailty of the couple makes manipulation too delicate; also the mechanical strength of the wires is so small that they are unable to support the weld at high temperatures.

The other quantity over which one has a measure of control is the emissivity of the thermocouple. In the case of the platinum–rhodium wire, e is very small indeed. Blackening the wire with carbon was tried with some success at low temperatures, but the coating disappeared above 800° C, and carbon is, on principle, to be avoided in many types of work. The use of certain refractory coatings however, while not achieving the emissivity value of carbon, could increase it by a factor of ten. At the same time, a fairly large bead of refractory could be used which would effectively increase the surface area of the thermocouple.

Alumina is not suitable as material for such a bead since it is transparent to infra-red rays; however, mullite is favourable, and in the present instance a thermocouple sheath was used, ground to a powder and mixed with a trace of Canada balsam in toluene. The paste so made could be moulded into a bead of 3 mm diameter on the thermocouple weld, which after firing at 1400° C produced a satisfactorily hard and adherent sheath. A calibration with this couple, in fact, showed a slight over-correction, small negative values of ΔT being obtained, which, however, still showed a peak around 300° C and disappeared above 600° C. This indicates that the mullite bead was too large, and more heat was lost by conduction along the specimen holder than through the thermocouple.

By careful adjustment of the size of the thermocouple sheath, and standardization, as far as possible, of the size of the specimen, it should be possible to arrive at a condition for which in practice no, or only a small, temperature correction is needed. Even so, this should always be checked by calibration, and periodic recalibration of the thermocouple during its working life is most desirable in order to be able to correct for aging effects.

Another possible way of reducing C would be to use a base-metal thermocouple, such as chromel-alumel, instead of the platinum/platinum–rhodium one. This would offer a certain advantage in reducing the thermal conductivity, and in increasing the emissivity as well as the electromotive force produced; the base-metal couple is, however, generally inadmissible in cases where an oxidizing atmosphere may be present in the camera (e.g. air or an inadvertent leak).

Apart from the reduction of the diameter of the thermocouple wires, and the artificial increase in the size of the weld or its emissivity, a number of other systems may be suggested for the reduction of ΔT. These are shown schematically in Fig. 5.

The cup, foil and ring all aim at increasing the area exposed to radiation, without adding an undue amount of weight. The cup and foil would be made of platinum, the ring may consist of the two thermocouple elements twis together. The spiral, loop and coil (the latter taken out the sheaths through side holes and wound round it) intended to reduce the temperature gradient in the vicin of the weld, by effectively increasing the hot-length of wi These methods have not been tried in the present investigati because there are practical objections from the viewpoint

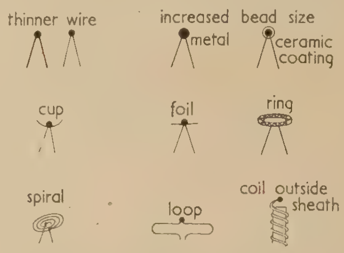


Fig. 5. Some alternative thermocouple designs for a high-temperature camera

block-specimen mounting, mechanical stability, and constan of positioning; also the reduction of the diameter of t thermocouple wire, coupled with the use of a refracto sheath, offered a simpler solution of the problem. They a however, put forward for consideration in any futu redesign.

The principle of a ring-shaped thermocouple has been us in Hume-Rothery and Reynold's work,(5) and, in the fo of two ring couples located each end of the wire samp developed by Basinski, Pearson and Christian(12) (applied work on manganese by Basinski and Christian(13)).

COLLATION OF DATA

It was thought that a brief note on other methods calibration may here be welcome, and this is given in Appendix below. This also contains a collection of so thermal expansion data for pure metals, in the form equations which might be used in preparing reference grap or tables.

Reliable data available are still very scarce, and it wou seem highly desirable to extend this information; if incidental suggestion may be permitted, it would be mo valuable to all those working in the X-ray high-temperatu field, if a small compendium (or index) could be organiz and published, to cover both standard dilatometric a transformation point data, and to which contributions cou be invited.

CONCLUSIONS

It is concluded that, by reducing the thickness of t thermocouple wires and possibly by other means, the te perature correction required can be largely eliminated; t need for camera-calibration should, however, be emphasiz wherever it is not possible to have the thermocouple in dire contact with the specimen.

ACKNOWLEDGEMENTS

The writers wish to express their thanks to Mr. R. Jewell, of The Sheffield Smelting Co. Ltd., and Mr. T. Lan of Land Pyrometers Ltd., for helpful discussions, and the appreciation to Mr. D. A. Oliver, Director of Research, Th B.S.A. Group of Companies, for his interest and encourag ment.

REFERENCES

1) GOLDSCHMIDT and CUNNINGHAM. *J. Sci. Instrum.*, **27**, p. 177 (1950).

2) PEISER, ROOKSBY and WILSON (Editors). *X-Ray Diffraction by Polycrystalline Materials*, Chapter 9 (Goldschmidt), p. 250 (London: The Institute of Physics, 1955).

3) BERRY, HENRY and RAYNOR. *J. Inst. Metals*, **78**, p. 643 (1951).

4) BASINSKI, HUME-ROTHERY and SUTTON. *Proc. Roy. Soc. A*, **229**, p. 459 (1955).

5) HUME-ROTHERY and REYNOLDS. *Proc. Roy. Soc. A*, **167**, p. 25 (1938).

6) SCHEEL. *Z. Phys.*, **5**, p. 167 (1921).

7) JAY. *Proc. Phys. Soc.* [*London*], **45**, p. 635 (1933).

8) ESSER and EUSTERBROOK. *Arch. Eishw.*, **14**, p. 341 (1941).

9) WORTHING. *Phys. Rev.*, **10**, p. 638 (1917).

0) GOLDSCHMIDT and LAND. *J. Iron Steel Inst.*, **155**, p. 221 (1947).

1) METCALFE. *Brit. J. Appl. Phys.*, **1**, p. 256 (1950).

2) BASINSKI, PEARSON and CHRISTIAN. *J. Sci. Instrum.*, **29**, p. 154 (1952).

3) BASINSKI and CHRISTIAN. *Proc. Roy. Soc. A*, **223**, p. 554 (1954).

4) WILSON. *Proc. Phys. Soc.* [*London*], **53**, p. 235 (1941).

5) EDWARDS, SPEISER and JOHNSTON. *Rev. Sci. Instrum.*, **20**, p. 343 (1949).

6) OWEN. *J. Sci. Instrum.*, **26**, p. 114 (1949).

7) PEASE. *J. Sci. Instrum.*, **32**, p. 476 (1955).

APPENDIX

Note on other methods of calibrating high-temperature cameras

Calibration of power input. Of the methods of calibrating e temperature reading of high-temperature cameras that of y(7) was probably the simplest. The power input to the rnace was related to the temperature, derived from the ttice spacing of silver. An accuracy of ±5° was claimed r this method, which had the advantage of dispensing with thermocouple.

This may be an excellent method for high resistance rnaces. However, when the resistance of the furnace is of e order of 1 Ω (at room temperature), the calibration may ange gradually, as the resistance of the furnace may alter wing to evaporation or contamination. In one example of e writers' experience the resistance increased by 50% over period of three months. Where the voltage drop on the e and at terminals is appreciable, this will cause a larger action of the observed power to be dissipated in the furnace.

Calibration by melting points. Wilson(14) calibrated his mera by observing the temperature at which pure metals elted. The melting point was determined by the disppearance of the diffraction pattern.

Basinski and Christian(13) also used the melting point ethod of calibration. Here the material used was mannese, the substance actually under investigation, and its elting was observed visually.

Calibration by transition points. Calibration by transition ints of pure substances or standard alloys presents the difficulty that there are not many suitable materials and especially that the important lower temperature range (room temperature to 800° C) is not at all well represented. Also temperature/phase hysteresis effects frequently occur, and titanium, uranium, zirconium and thallium are all so easily oxidized that either an extremely high vacuum or an inert atmosphere would be essential; cobalt is too sluggish, while manganese with its several transformations and iron (A_3 and A_4 point), quartz and a few other refractory oxides and inorganic compounds are acceptable, each however with its special qualifications. Again, transformations in alloys and certain steels, the eutectoid change in carbon steels, allotropy in intermetallic compounds and carbide structure are suitable, provided composition-changes can be excluded.

On the whole this method and the preceding one appear to be more time-consuming and less certain than that of using the expansion of a pure metal; rapid diffusionless transformations are, however, very valuable, particularly if a high-temperature camera is used with a Geiger diffractometer.

Internal calibration. For "internal calibration" the specimen can be coated on a standard wire (e.g. platinum), the lattice spacing of which is used to give the temperature directly. This is an excellent method for ceramic powders. Metal powders obviously cannot be coated on to metal, because of possible alloying, but they could be mixed with a refractory powder and coated on a silica fibre (up to 1000° C) or directly on to a simple-oxide ceramic rod (e.g. magnesium oxide or beryllium oxide). This is less useful, except for approximate temperature measurement, since the expansion coefficients of refractories are not large enough to make the method sensitive.

The use of an optical pyrometer is also possible(15), although the accuracy is not high, and certain obvious conditions have to be fulfilled: the specimen must be viewable through a transparent window, the pyrometer must be calibrated through this window, and the method works only in the incandescent range.

Owen's method(16) of alternating exposure of a separate standard specimen should here be mentioned, and although this was designed for block samples, it would be adaptable to powder ones, for instance by a double fibre made by one-sided coating of a rotating standard wire.

Some data on thermal expansions of pure metals suitable for X-ray high-temperature camera work

Expansion equations

Metal	*Equation*	*Reference*
Ag	$l_t = l_0(1 + 19{\cdot}494 \times 10^{-6}t + 1{\cdot}038 \times 10^{-9}t^2 + 2{\cdot}375 \times 10^{-12}t^3)$	(8)
Pt	$l_t = l_0(1 + 8{\cdot}988 \times 10^{-6}t + 1{\cdot}065 \times 10^{-9}t^2 + 0{\cdot}126 \times 10^{-12}t^3)$	(8)
Au	$l_t = l_0(1 + 14{\cdot}146 \times 10^{-6}t + 1{\cdot}585 \times 10^{-9}t^2 + 1{\cdot}093 \times 10^{-12}t^3)$	(8)
Cu	$l_t = l_0(1 + 16{\cdot}733 \times 10^{-6}t + 2{\cdot}626 \times 10^{-9}t^2 + 0{\cdot}91 \times 10^{-12}t^3)$	(8)
Al	$a_t = 4{\cdot}0392 + 0{\cdot}00901\,(t/100) + 0{\cdot}000432\,(t/100)^2$	(14)
W	$L_T = L_0[1 + 4{\cdot}44 \times 10^{-6}(T-300) + 4{\cdot}5 \times 10^{-11}(T-300)^2 + 2{\cdot}20 \times 10^{-13}(T-300)^3]$	(9)

Where l_t and l_0 = length of specimen at t° C and 0° C respectively; a_t = spacing in kX; L_T and L_0 = length of specimen at T° K and 300° K respectively.

A calorimeter for measuring energy absorption from pile radiatio

By A. R. Anderson, B.Sc., Ph.D., A.R.I.C., and R. J. Waite, Atomic Energy Research Establishment, Harwell, Be

[*Paper first received* 5 *September, and in final form* 11 *October,* 1955]

An adiabatic calorimeter has been designed for the measurement of energy absorption from pile radiation. Some of the unusual problems encountered in this type of calorimetry are discussed. The preliminary work leading to a suitable design of calorimeter is summarized and full descriptions of the instrument and measurement techniques are given. Electrical calibrations of three samples with widely different thermal conductivities have demonstrated the satisfactory behaviour of the calorimeter over a wide range of power inputs. The results of some measurements in the Harwell pile BEPO are briefly discussed.

When a chemical system is irradiated the changes that occur in it are related to the amount of radiation energy absorbed. Measurement of this energy has most frequently been made by replacing the system under investigation with a gas-filled ionization chamber, and relating the energy absorption in a gas to that in the system by calculations based on the physical processes of energy absorption for the type of radiation used. This method of reasoning, however, has many uncertain links. Even in the case of electromagnetic radiation, where the relationship has been most intensively studied, recent calorimetric measurements(1,2) have shown that ionization chamber values can be in error by as much as 20% unless complex corrections are applied for certain geometrical factors. In the case of neutron irradiation the large and irregular variations of neutron scattering and absorption cross-sections of the elements add further difficulties to the calculation. When, as in pile radiation, a variable amount of γ-radiation is also present, the process becomes so uncertain as to be practically valueless. To avoid these complications and uncertainties it is desirable to measure directly the energy absorbed in a material when exposed to pile radiation.

Materials in the pile absorb energy chiefly by the slowing down of fast neutrons (energy greater than 10^3eV) and by the absorption of γ-rays produced during fission and from the decay of fission products. With the exception of some work by Bopp and Sisman,(3) based on unpublished calorimetric data (from D. M. Richardson) for the reactor at Oak Ridge National Laboratory, quantitative studies with pile radiation have all been related to thermal neutron dose received by the system. Since low energy thermal neutrons contribute little to energy absorption processes in many materials, however, the thermal neutron dose does not necessarily bear a constant relation to energy absorption even for a single material. Thus quantitative comparisons with effects of other types of radiation or with other systems are not possible on the basis of thermal neutron dose. This paper describes a calorimeter designed to determine directly the energy absorbed in materials during irradiation in the Harwell pile BEPO.

NATURE OF THE PROBLEM

A calorimetric measurement in a nuclear reactor is subject to certain unusual difficulties which do not arise in ordinary calorimetry. These problems are summarized with particular reference to the graphite moderated pile BEPO.

The calorimeter proper will consist of a suitable specimen of the material, the energy absorption of which is being studied, and this will be called the sample. The rest of the calorimeter assembly must be made from materials chosen with regard to their nuclear properties and stability to radiation as well as to their thermal properties. Copper and silver, which are often used for calorimeter heating jack on account of their high thermal conductivities, are suitable for a calorimeter assembly which is exposed to radiation. Both these materials have large neutron abs tion cross-sections for nuclear reactions which prod radioactive species. This means that it will be difficult handle the calorimeter after irradiation. In addition, contribution to energy absorption from these indu activities will constitute a small error which has to be c rected. The most suitable metal to use in such a calorime is pure aluminium which combines reasonable nucl properties with a thermal conductivity just over half that copper. Other problems are presented by the breakdown certain electrical insulating materials and of vacuum sea compounds under irradiation.

Calorimeter measurements in a nuclear reactor necessit remote control so that temperature measurements must made with thermocouples or resistance thermometers. Th is also the mechanical problem of introducing the calorime into a small diameter experimental hole in the pile. need to measure energy absorption at various places in core and in the thermal column of the pile involves the des of a remote control system to move the calorimeter fr over a distance of about fifteen feet inside the experimen hole. For some purposes it will be necessary to ma measurements with the calorimeter inside a hollow urani cylinder. This imposes a restriction of $1\frac{1}{2}$ in. on the maxim overall diameter of the calorimeter assembly.

In order that measurements of energy absorption in vari materials made at different times can be compared quanti tively it is necessary to determine the thermal neutron f and the energy distribution of the neutrons, namely, neutron spectrum. This is done by the use of nuclear physi monitors, i.e. materials which undergo specific nuc reactions with neutrons to produce radioactive species wh can be characterized by standard radiation counting te niques. Thus each calorimetric measurement must accompanied by such monitors usually in the form of th foils. This involves the delivery of these foils to a rep ducible position relative to the calorimeter at any locati inside the experimental hole.

Measurements in the core of the reactor present a particu problem. In a heterogeneous graphite moderated pile su as BEPO the uranium rods are arranged $7\frac{1}{4}$ in. apart in lattice system. In order to detect possible variations energy absorption per unit of thermal neutron dose caus by varying distances of a material from the uranium ro the calorimeter sample must be small compared with lattice pitch ($7\frac{1}{4}$ in.) and, within the reacting core of the p accurate location of the calorimeter is essential. The sam needs also to be small so that the whole of it is subject to uniform radiation flux.

PRELIMINARY STUDIES

The dimensional restrictions mentioned above indicated at vacuum heat insulation would be an essential require-nt of the calorimeter. In addition to space limitations, ssible changes in the thermal conductivities of solid lagging terials under pile irradiation make most materials unsatis-ctory. The choice in design resolved itself into one between non-isothermal calorimeter with an adiabatic or an iso-ermal jacket. With this latter type in the pile, the jacket uld be maintained at a constant temperature slightly ove ambient temperature until a constant temperature ference was recorded between the sample and jacket. evious electrical calibration of the calorimeter would late this steady state temperature difference to the rate of ergy absorption in the sample. With the adiabatic type, electrical heater wound on the jacket wall would be used continually adjust the temperature of the jacket to that the sample. The measured rate of temperature rise of e sample would be related to the rate of radiation energy sorption by previous electrical calibration.

The adiabatic type of calorimeter seemed more favourable at the choice was determined by the results of a series of sts on two substances of widely differing thermal conduc-vities, aluminium and polythene. Solid cylindrical samples in. in length, ½ in. diameter) of these two materials were ound with a fine gauge copper heater accommodated in a lical spiral groove cut into the sample surface. Provision as made for the location of copper/constantan thermocouples three positions: on the surface, in the centre, and near the p of the sample.

The sample, with the thermocouples in position, was sus-ended by Nylon threads inside an aluminium can which as evacuated to a pressure of 10^{-3} mm of mercury. To btain constant temperature surroundings, the aluminium n with the thermocouple cold junctions strapped to the tside was completely immersed in crushed ice contained a Dewar flask, and the whole allowed to reach temperature uilibrium. A known rate of electrical energy input was en applied to the sample and its temperature followed on e three thermocouples until a constant temperature fference was recorded between the surface of the sample d the can. The electrical heater was then switched off and e cooling curve of the sample determined.

The large temperature differences which were found in the lythene sample showed that to use a calorimeter with an othermal jacket would make the electrical calibration tremely uncertain. In the pile, radiation energy will be sorbed uniformly in a small sample, whereas in the electrical libration energy is absorbed non-uniformly from a heater inding. In the latter case the reading of any thermocouple ill not correspond to its reading under conditions of uni-rm energy absorption. As many of the substances in which uantitative radiation effects are extremely important, e.g. lythene, have low thermal conductivities, a calorimeter ith an adiabatic jacket is to be preferred. The temperature ifferences in the polythene sample are proportional to the mperature difference between the sample surface and the n. Consequently with a very small temperature difference ±0·025° C (i.e. approximately ±1 μV with copper/con-antan thermocouples) between the sample and jacket, mperature differences in the sample are negligible.

There is another serious objection to the use of a calorimeter ith an isothermal jacket. The steady state temperature fference is highly dependent on the air pressure in the gion 10^{-2}–10^{-3} mm of mercury and there was no certainty at a steady pressure could be maintained in a vessel which had to be designed to move freely inside the pile to a distance of 40 ft from the pumps. In consequence, the use of this method would involve electrical calibrations over a range of pressures as well as of temperature and power inputs, and the pressures would have to be measured accurately in the calorimeter itself. The latter would be extremely difficult. These considerations led to the design of an instrument which would be used purely as an adiabatic calorimeter.

The cooling curves for both the aluminium and polythene samples were found to obey Newton's law of cooling very closely when the temperature differences between the sample and its surroundings were less than 2° C. Consequently, from the rates of cooling of the two samples, the maximum error in measuring different rates of energy deposition could be calculated, assuming that the geometry of the designed adiabatic calorimeter was similar to that used in the above tests. Assuming that a maximum temperature difference of 0·025° C could occur unobserved between the surface of the sample and the adiabatic jacket, it was calculated that the error in measuring the rate of temperature rise of a polythene sample would vary from 0·2 to 10% when the power inputs were respectively 60 and 1·2 mW. The errors in measuring the rates of temperature rise of an aluminium sample with corresponding power inputs would be 0·12 and 6%. It was considered that, in the pile, these power inputs of 60 and 1·2 mW for aluminium and polythene samples of slightly different sizes would correspond approximately to thermal neutron fluxes of 2×10^{12} neutrons per cm^2 per second (core) and 4×10^{10} neutrons per cm^2 per second (thermal column) respectively. In practice the temperature difference between the sample and jacket will be distributed symmetrically around zero within the limits ±0·025° C so the actual error of the measurement will be less than that quoted. The error of a measurement will be given by the deviation of the points from the best straight line calculated to fit a plot of temperature against time.

By maintaining the temperature difference between the sample surface and jacket within the limits of ±0·025° C it is possible to calibrate accurately a sample such as polythene using a heater winding. This is in accord with the findings of Swietoslawski, Rybicka and Solodkowska(4) in their measurements of specific heats of solids and liquids using the adiabatic method. They showed that in spite of the poor thermal conductivities of some substances, e.g. pyridine, it was possible to attain temperature equalities inside the calorimeter.

In order to maintain temperature differences between the sample surface and the jacket within the limits of ±0·025° C it is necessary to reduce heat losses by conduction along lead wires to a minimum. Consequently it was decided to use fine gauge thermocouples wires in the calorimeter, copper (46 s.w.g.) to constantan (32 s.w.g.). These two gauges in the different wires have approximately the same specific resistance and thermal conductivity and would constitute only a small fraction to the heat capacity of the sample. As measurements in the pile would require lead wires some fifty feet long the high resistance of these fine wires would adversely effect the sensitivity of the galvanometer, and consequently the measurements of potential difference. It was therefore intended to reduce the overall resistance of the thermocouple circuits by joining the fine wires to thicker lead wires just outside the calorimeter. In order to maintain these changeover junctions at a uniform temperature, and thus minimize the danger of irreproducible junction potentials, it was decided to locate these insulated junctions inside an aluminium block of reasonably high heat capacity. A series of tests was therefore carried out to investigate if these junctions could be made reproducibly, and if the thermocouples themselves were reproducible over a length of fifty feet. The results of these tests both in and out of the pile are summarized in Table 1.

Table 1. *Tests on the reproducibility of thermocouple junctions*

Reference junctions in melting ice;
A: changeover junctions inside aluminium block;
B: changeover junctions outside aluminium block;
A–B: comparing changeover junctions inside with those outside the aluminium block.

	Ambient temperature (°C)	*Potential differences between any two thermocouples (μV)*					
		A		*B*		*A–B*	
		Average	*Maximum*	*Average*	*Maximum*	*Average*	*Maximum*
Out of pile	25	<0·5	<1	<1	2	<1	2
	80	3	7	4	7	5	8
In pile	25	<0·5	<1	<1	1	1	2
	80	2–3	4	6	14	30	64

From the results of the tests it was considered more satisfactory to place the changeover junctions inside an aluminium block. It was estimated that in the centre of pile a temperature difference of ±0·1° C (i.e. 4 μV) betw the sample and jacket would give a maximum error in d mining the rate of temperature rise of about ±0·5% aluminium and about ±1% for polythene.

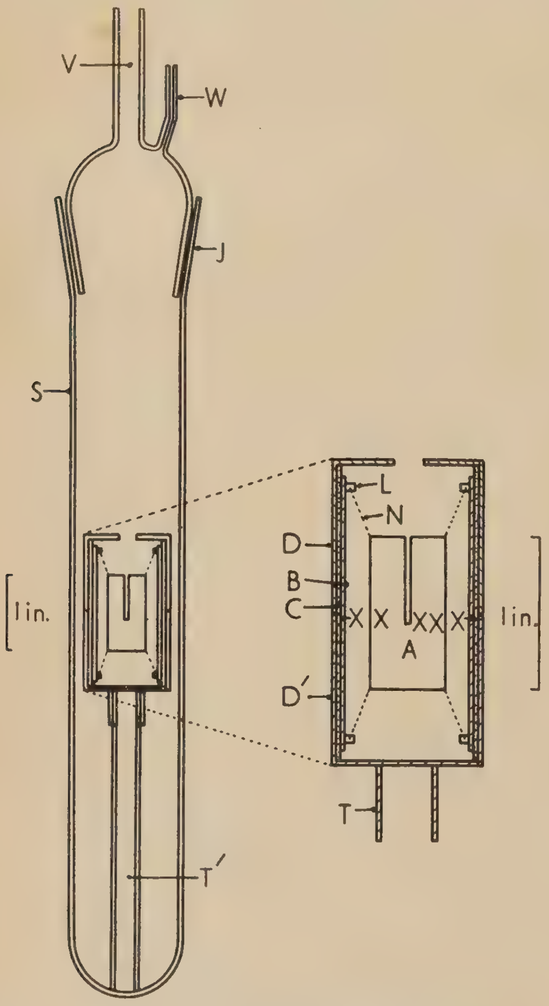


Fig. 1. Pile calorimeter cross-section

A, sample; *B*, inner aluminium cylinder; *C*, outer aluminium cylinder; *D* and *D′*, close fitting aluminium lids; *J*, B40 standard joint; *L*, suspension lugs; *N*, Nylon suspension threads; *S*, silica vessel; *T*, aluminium tube; *T′*, silica tube; *V*, tube for vacuum line connexion; *W*, tube to bring out electrical leads; *X*, thermocouple position.

DESCRIPTION OF CALORIMETER

The final design of calorimeter (Figs. 1 and 2) consists sample (of the material the energy absorption of whic being studied) suspended by Nylon threads inside an minium jacket which is, in turn, located inside a silica ve This silica vessel is evacuated by continuous pumping du a calorimetric measurement. The calorimeter is adiabatically. During the course of a measurement

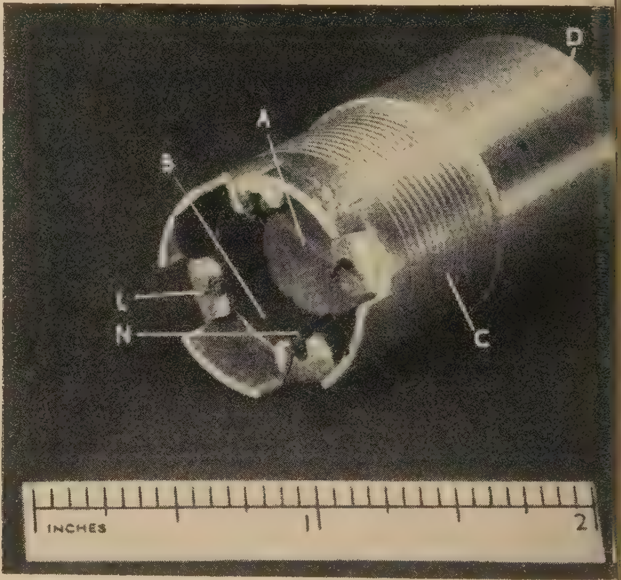


Fig. 2. Sample suspended inside heating jacket

A, sample; *B*, inner aluminium cylinder; *C*, outer aluminiu cylinder; *D*, upper aluminium lid; *L*, suspension lugs; *N*, Nylo suspension threads.

electric heater wound on the aluminium jacket is used maintain the temperature of the jacket equal to that of sample within the limits ±1 μV (i.e. ±0·025° C). Te perature differences between the sample and jacket measured by arranging the two appropriate thermocoup in opposition across a galvanometer of known sensitiv when zero deflexion denotes temperature equality. A th thermocouple is used to measure the temperature rise of sample caused either by energy deposition from pile radiati by known rates of electrical energy input during cali-ation.

Samples *A* (Figs. 1 and 2) of solid materials cylindrical in rm (1 in. length by ½ in. diameter) have twin helical spiral ooves cut into their surface to accommodate a fine copper ating wire (46 s.w.g.) for calibration purposes. Six longi-dinal grooves on the sample take the Nylon suspension reads *N* and provide a means of locating the surface thermo-uples. Other thermocouple positions *X* are provided by e holes drilled down the centre and across a diameter ar the top of the sample. This latter position was used to amine temperature gradients in the sample but is not rmally used during calibration and measurement. Sample ılbs for liquids have been designed but not yet tested.

The heating jacket consists of two thin aluminium cylinders, and *C*, shrunk together so that grooves down the inside rface of *C* provide thermocouple positions between the ncentric cylinders. The outer surface of the jacket in. length, 1 in. diameter) is machined in the same way as e sample to accommodate a heater winding. In order to inimize end losses of heat from the calorimeter, two extended uminium lids *D* and *D′* are machined to fit closely over the ngth of the heating jacket. In this way the sample is almost mpletely enclosed by the jacket. A small aluminium tube welded to the bottom of the lower lid *D′* fits snugly over the in silica tube *T′* thus locating the assembly within the outer lica vessel *S*. The dimensions of the silica tube *T′* are such at heat losses by conduction down it are of the same order those down the lead wires. Maximum heat losses from e jacket by conduction are calculated to be about 16% of e total heat losses by conduction and thermal radiation. wo tubes *V* and *W* through the cone of the B40 joint *J* on e silica vessel serve as a connexion to the pumping line d to bring out the electrical leads. The design of calori-eter is such that a fresh assembly is required for each mple. This means that components of the calorimeter hich are liable to deteriorate under irradiation, e.g. enamel sulation on the thermocouple and heating wires, are com-letely replaced before each series of measurements with a fferent sample.

ASSEMBLY AND MEASUREMENT TECHNIQUES

In the assembly of the calorimeter, lead wires from the ample and from the jacket are twisted together gently and oiled to increase the conductance path. The wires used in e calorimeter are enamelled and silk covered, which insula-on is stable to irradiation during the sojourn of the instru-ent in the pile. At all stages of the assembly electrical sulation is carefully checked. The lead wires are sealed to their exit silica tube with sulphur which is also used as a acuum sealing substance for the cone and socket joint. ulphur is the only material so far found to be effective under ile irradiation.

In order to move the calorimeter inside the pile a flexible aterial has to be used for the pumping line. Polythene ubing has proved to be satisfactory for this purpose. In e laboratory the calorimeter assembly can be maintained t a pressure of less than 10^{-3} mm of mercury by continuous umping through a polythene tube fifty feet in length, while the pile a pressure of $\leqslant 5 \times 10^{-3}$ mm of mercury can ormally be maintained. Symmetrical temperature control f ±0·025° C between the sample and jacket can be achieved uite readily up to pressures of 3×10^{-2} mm of mercury.

Before assembly, the resistance of the electric heater winding on the sample is measured by comparing the potential difference across the heater with that across a standard 1 Ω (±0·05%) manganin resistance. Measurements of potential are made with a decade potentiometer type 4025 (by H. Tinsley and Co. Ltd.) in conjunction with a galvanometer (by the Cambridge Instrument Co. Ltd.) capable of reading 1 μV. Current is supplied to the circuit from a heavy duty 6 V storage battery through a high resistance variable resistor. As copper has a fairly high temperature coefficient of resistance (0·38% per °C) the power inputs to the sample are kept low so that the temperature of the sample as measured by the surface thermocouples does not change by more than 0·1° C during the measurements. The resistance of the heater winding is accepted as the mean of five determinations. In the course of these measurements the greatest deviation from any mean value has been less than 0·5%.

For electrical calibration, current to the sample heater is supplied as in the resistance measurements. The resistance of the variable resistor is such that the maximum change in power input, caused by heater resistance changes, is only 0·5%. To correct for changes in the heater resistance the temperature coefficient of the copper heating wire was determined experimentally and found to be $3 \cdot 74 \times 10^{-3}$ per °C over the range 0–100° C. During the course of a calibration the current input into the sample heater circuit is measured at frequent intervals by determining the potential difference across a standard resistance in series with the heater winding. The power input can be maintained steady by this simple circuit within the limits of ±0·5%.

All temperatures are measured with copper-constantan thermocouples with their reference junctions strapped to an aluminium block in crushed ice, contained in a Dewar flask. As these measurements are concerned with temperature differences, and not with absolute temperatures, any convenient reference junction temperature can be used if it satisfies the requirement of stability during the course of a measurement. The Tinsley potentiometer and Cambridge galvanometer used in the resistance measurements are also used for measurement of thermocouple potentials. To facilitate adiabatic control between the sample and jacket the two appropriate thermocouples are arranged in opposition across a moving coil galvanometer with a sensitivity of 330 mm/μA at 1 m using a lamp and scale technique. Temperature equality is denoted by resultant zero deflexion. The jacket heater current is adjusted manually with a fine control circuit. Temperature control has been maintained within the limits ±0·0125° C at low power inputs (less than 15 mW) and ±0·025° C at higher power inputs to the sample.

CALIBRATION OF THE CALORIMETER

The calorimeter is calibrated electrically by measuring the rate of temperature rise at constant power inputs. The power input is given by the relationship.

$$\text{power input} = I^2R = \text{watts} \tag{1}$$

where I is the current in amperes and R is the resistance of the sample heater winding in ohms. The calibration value of the calorimeter sample is then calculated from the equation.

$$C(\Delta Q/\Delta t) = \Delta T/\Delta t \tag{2}$$

where $\Delta Q/\Delta t$ is the power input in milliwatts, $\Delta T/\Delta t$ is the measured rate of temperature rise in microvolts per minute, and C is the calibration value of the calorimeter sample in microvolts per minute per milliwatt.

The rate of energy deposition from pile radiation is then given by

$$(\Delta Q/\Delta t)_p = (\Delta T/\Delta t)_p/C \qquad (3)$$

where $(\Delta T/\Delta t)_p$ is the measured rate of temperature rise in microvolts per minute. This method of comparative measurements using electrical calibration is essential to eliminate calorimetric and thermometric errors. The thermocouples used in any calibration are checked to see that they agree among themselves, which is important in the case of thermocouples used for adiabatic control within the limits $\pm 0{\cdot}0125°$ C (i.e. $\pm$ 0·5 μV). In measurements with the calorimeter two thermocouples are fixed to the surface of the sample and two to the inner portion of the heating jacket so that various combinations of these four thermocouples can be used to test the calibration value.

The performance of the calorimeter has been tested by the calibration of three samples of widely different thermal conductivities; aluminium, graphite and polythene. In each calibration the straight lines obtained by plotting temperature against time have been analysed statistically by the method of least squares. The errors in the slopes of more than twenty-five calibration curves range from a minimum of $\pm 0{\cdot}21\%$ to a maximum of $\pm 1{\cdot}6\%$. The relationship between power input and rate of temperature rise has been found to be linear over a wide range of power inputs for these three samples (Fig. 3). The linearity of these relationships showed that even at low power inputs, net heat losses from the sample were negligible. Thus the close-fitting, extended aluminium lids served the same purpose as the cavity heater of Lazo, Dewhurst and Burton(2) in their calorimetric work with a cobalt γ-source. Without the special precaution of a cavity heater to reduce heat losses they found that the calibration, expressed as the ratio of microvolts temperature rise to joule energy input, increased slowly with increasing power input.

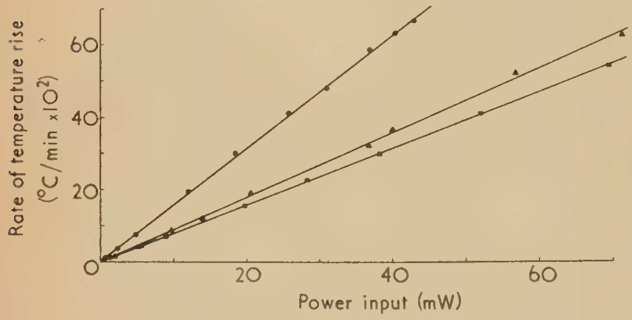


Fig. 3. Calibration curves for three calorimeter samples

● = graphite.
▲ = polythene.
■ = aluminium.

The calibration values of the three samples have been calculated and compared with those determined experimentally. In order to make this comparison a number of copper/constantan thermocouples were calibrated over the range 0–100° C and were found to give an almost linear response of 41 $\pm$ 0·2 μV/°C. The correction for heating the small amount of residual air in the calorimeter was negligible(4) but allowances were made for the heat capacities of the lead wires, thermocouples, suspension threads and heating coil. In these calculations half the lengths of the wires and Nylon between the sample and jacket was considered to be part of the heat capacity of the sample, and half the heat gener in the lead wires within the adiabatic jacket was consid to be supplied to the sample. The sum of these var corrections was small, amounting to a maximum of only in the worst case. Good agreement was found between calculated and determined calibration values in the th cases (Table 2). Such agreement is gratifying, but, as Whi points out, an experimental calibration is generally m accurate than a calculated calibration as it largely elimin any systematic errors of the calorimeter.

Table 2. *Calibration values for three calorimeter sampl*

Substance	*Specific heat (20° C) (cal/g)*	*Calibration value* Determined *(°C per min per mW × 10³)*	*Calibration value* Calculate
Aluminium	0·214(6)	7·86 ± 0·04	7·78
Graphite	0·170(6)	15·6 ± 0·15	15·7
Polythene	0·55 (7)	8·97 ± 0·14	8·8

In order to reproduce the pile conditions as closely possible each sample is calibrated before irradiation ove temperature range equivalent to that across the pile. calibration is repeated after irradiation with the calorim in the pile but with the pile closed down. This latter c bration is to determine if the thermal or electrical proper of calorimeter components have been affected by irradiat

PILE EXPERIMENTAL ASSEMBLY

The equipment for introducing the calorimeter into pile is illustrated in Fig. 4. The whole pile experimen assembly is lowered into and removed from the pile means of an overhead crane. The outer aluminium tube which fits closely into a vertical experimental hole in the p is closed at the top with a steel plug *SP* to provide shiel from the pile radiation. Two holes, *H*, *H′* through the are curved in such a way that they do not permit the pass of pile radiation but can be used to bring out wires a flexible tubes from the calorimeter. The calorimeter C held in an aluminium cradle *CR* which is moved along gu tubes *GT*, *GT′* inside the outer aluminium tube *O*. T cradle and foil can *F* are motivated by two independent w friction drive mechanisms *DR*, *DR′* which are opera behind lead shielding on top of the steel plug. The car containing the monitoring foils can thus be delivered to calorimeter in any position. A stop *FS* on the cradle ensu that the foil can is located in the same position relative the calorimeter sample at any position of the cradle. top of the plug the foil can is received behind lead shieldi a portion of which is removable so that foils can be chang quickly and conveniently. The electrical lead wires a polythene vacuum lead are both brought through the pl inside a common polythene tube. This greatly facilita movement of the cradle inside the assembly and protects t insulation on the wires in their movement through the pl The position of the calorimeter in the pile assembly is in cated by marks made on the outer polythene tubing. Th marks are made with reference to two fixed positions, t distances of which from the top of the plug are kno accurately. By keeping the polythene taut during marki and subsequent operation in the pile the calorimeter positi is known within one inch with respect to the top of the pl and to the location of any uranium rod. To facilitate loadi and unloading the calorimeter, upon removal from the pi arge panel near the top of the outer aluminium tube is away.

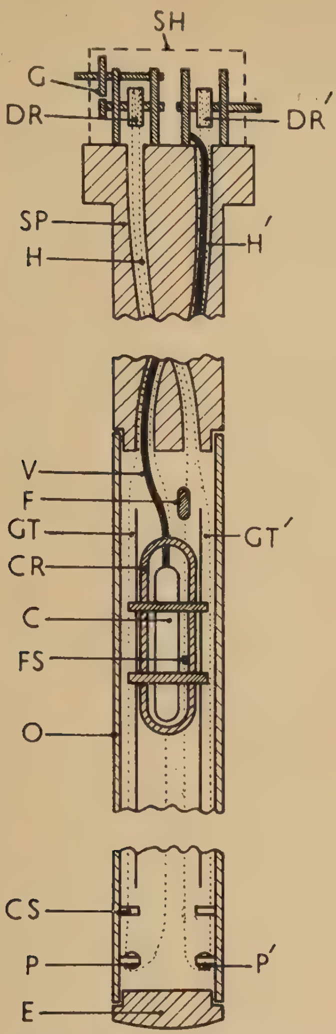


Fig. 4. Pile experimental assembly schematic section

(Not to scale; overall length 20 ft).

C, calorimeter; *CR*, calorimeter cradle; *CS*, cradle stop; *DR*, drum drive for foil can; *DR′*, drum drive for cradle; *E*, shaped end piece; *F*, foil can; *FS*, foil can stop; *G*, gears; *GT*, *GT′*, guide tubes; *H*, *H′*, curved holes through plug; *O*, outer aluminium tube; *P*, *P′*, pulleys; *SP*, steel plug; *SH*, lead shielding; *V*, vacuum lead.

MEASUREMENTS IN THE HARWELL PILE BEPO

Measurements in the pile BEPO have been completed h aluminium, polythene and graphite samples. In each case the relationship between rate of energy absorption and thermal neutron flux has been found to be linear both across the core and along the thermal column. The proportionality constant changes in going from the core to the thermal column where the energy contribution from fast neutron scattering becomes insignificant. These results will be discussed in detail when measurements are completed with selected materials. When the results are available and the neutron spectrum and γ-flux have been accurately determined, it should be possible to relate these data with known physical properties of the materials, such as neutron scattering cross-sections and mass absorption coefficients for γ-rays. The complete series of measurements will take some months to complete but sufficient has already been done to show that the instrument described here is reliable, accurate and fulfils the exacting requirements demanded.

ACKNOWLEDGEMENT

It is a pleasure to acknowledge the value of the advice and encouragement given by Mr. J. Wright during the course of this work.

REFERENCES

(1) Hochanadel, C. J., and Ghormley, J. A. *J. Chem. Phys.*, **21**, p. 880 (1953).

Donaldson, D. M., and Miller, N. *Quantitative Studies of Radiation Induced Reactions* (Paper presented at Reunion Annuelle de la Societe de Chimie Physique; Paris, June 1955).

(2) Lazo, R. M., Dewhurst, H. A., and Burton, M. *J. Chem. Phys.*, **22**, p. 1370 (1954).

(3) Bopp, C. D., and Sisman, O. *Radiation Stability of Plastics and Elastomers*, ORNL 928 (1951) and ORNL 1373 (1954) (Tennessee: Oak Ridge National Laboratory).

(4) Swietoslawski, W. *Microcalorimetry* (New York: Reinhold Publishing Cor., 1946).

(5) White, W. H. *The Modern Calorimeter* (New York: Chemical Catalog Co., 1928).

(6) Hodgman, C. D. (Ed.). *Handbook of Chemistry and Physics*, 13th ed. (Cleveland, Ohio: Chemical Rubber Publishing Co. 1947).

(7) *Alkathene for Injection and Compression Moulding.* Publication I.S. No. 280 (London: Imperial Chemical Industries Ltd., 1951).

The principles and apparatus of the injection system of the Birmingham proton synchrotron

By C. A. Ramm, Ph.D., A.Inst.P.,* University of Birmingham

[*Paper received* 23 *August*, 1955]

An outline is given of the principles used in the injection system of the Birmingham proton synchrotron which make the injection process relatively automatic and free from the necessity of a primary proton beam with an energy of great stability. A simple analysis is made of particle collection in the absence of the radio-frequency acceleration. The basic components and methods of monitoring the injection system are described.

In this paper it is proposed to describe the purpose and operation of the principal parts of the injection apparatus of the Birmingham synchrotron. An experimental analysis of the process of injection will be published.(1)

The other large proton synchrotrons have injection energies about an order of magnitude greater than in Birmingham. At first sight this might seem unusual, but it will be recalled that the difficulty of the injection of particles of energy E into a synchrotron is inversely related to the magnitude of the mean orbit shrinkage, Δr per revolution, at injection. If betatron retardation is neglected

$$\Delta r = -\pi r^3 \dot{B}_0/(1-n)E \qquad (1)$$

where r is the mean orbit radius, $\dot{B}_0$ is the time rate of rise of the magnetic field and n is the field index. For this machine, with $r \simeq 460$ cm, $\dot{B}_0 \simeq 15\,000$ gauss/s, $n \simeq 0{\cdot}7$ and $E \simeq 460$ keV we find $\Delta r \simeq 3$ mm. Despite the high injection energies in the other machines, the term in r^3 and their generous geometrical dimensions keep Δr much larger than 3 mm.

It is possible that for this synchrotron the choice of a much higher injection energy could have presented a serious technical embarrassment to simple techniques. However, it is not suggested that the present value is an optimum one since other considerations as well as injection energy are involved if the maximum particle output from a synchrotron is to be obtained.

In Birmingham, the exploitation of elementary principles in determining the best instant for commencing the radio-frequency acceleration has made the accurate stabilization of the injection energy redundant.

THE TRAJECTORIES OF INJECTED PROTONS

Suppose that Fig. 1 is a schematic plan of the synchrotron vacuum box, with the magnetic field perpendicular to the paper, and assume that a continuous beam of protons passes down the electric guide plates G, which present a direct tangential passage to the chamber around the proper time of injection. Consider the change in trajectories as the magnetic field rises. At a certain instant, when the magnetic field is low, the injected beam will strike the outer wall of the vacuum box, perhaps at a point A, which point will run anti-clockwise around the box as the field increases. Eventually the magnetic field intensity will be such that injected particles will describe a nearly circular orbit and return almost to the tip T of the guide plates. It is useful to define the instant of time at which these particles left T as t_s, the start of injection. It will be assumed that at t_s the mean orbit appropriate to the particular injection energy shri past T, and that the injected beam is instantaneously mo energetic, an experimentally observed fact.

Subsequent to instant t_s particles are able to spiral i the machine. For tangential entry the instantaneous am tude of horizontal oscillation for any particular particl equal to the radial distance from T to the mean orbit at moment of entry. At a certain instant t_c the horizo oscillation will carry the injected particles across the vacu chamber, so that they just strike the inner wall at a poin which will be at an azimuthal distance of $\pi(1-n)^{-\frac{1}{2}}$ fr T in the direction of circulation. Protons which enter machine later than t_c will circulate less than this and strike the wall at some point clockwise from I around inner wall of the vacuum box. At the instant t_c the m orbit appropriate to the injection energy is very nearly h way radially between T and I. It is easy to see in princi and it has been experimentally verified, that this is optimum instant for initiating the radio-frequency accele tion. Thus, provided a radio-frequency generator ex which, throughout the magnetic cycle, produces a freque appropriate to the circulation of protons on the mid-o in the vacuum chamber, it may be gated at the appeara of a signal from a probe P_I at I to provide optimum accele tion of the injected particles, quite independently of injection energy. A technically trivial restriction, for particular case described, is that the injection energy must constant in the interval t_s to t_c. No advantage is to be gai in principle from the absolute stabilization, or even measurement, of the injection energy and the process injection and acceleration may be made automatic.

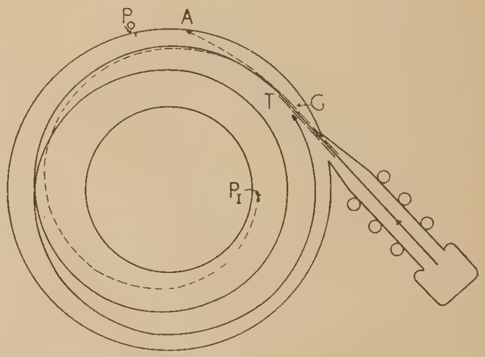


Fig. 1. Schematic plan of beam trajectories in vacuun box

For some purposes, particularly when the injection ene is raised after t_s, it is useful to have a probe P_0 situated a the outer wall of the vacuum box so that a signal can be tained shortly before t_s. While not as sound in principle the signal from P_I, it is found that the signal from P_0, in njunction with a suitable delay, may be used to give gating the radio-frequency acceleration which is in practice just automatic.

---

* Now at CERN Proton Synchrotron Group, Geneva, Switzerland.

It is useful to consider briefly, in Fig. 2, the nature and time lationship between the signals from P_0 and P_I in the absence any radio-frequency acceleration. For probes of width uch greater than that of the beam, the maximum current om P_0 is equal to the injected current, but the maximum om P_I is greater. The signal from P_0 is of an elementary ature and by differentiation of the trailing edge it is possible obtain an accurate timing signal. The signal from P_I is ore complicated. It consists of two components, a sharp gnal, the "main spike," which corresponds in time with t_c nd a longer signal due to the collapse of the spiralling beam n to P_I.

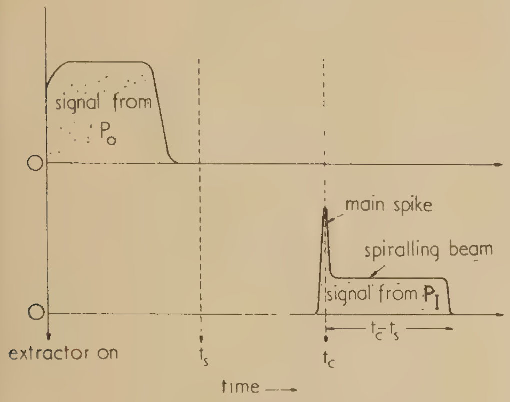


Fig. 2. Probe signals near injection

For any circulating particle of a particular instantaneous r value we have

$$Br = rB_0(r_0/r)^n \qquad (2)$$

here r_0 is the radius of the mean orbit of the particle, and e magnetic field has a value B_0 at a radius r_0. By differentiaon with respect to time the radial velocity of the mean orbit is

$$\dot{r} = [-r\dot{B}_0 + (r/r_0)^n d(Br)/dt]/(1-n)B_0 \qquad (3)$$

he small value of the time derivative of Br due to betatron tardation and the variation of $\dot{r}$ across the vacuum box ill be neglected. With the same parameters as before $\simeq 10^5$ cm/s.

All possible injected trajectories may be represented on a iagram (Fig. 3) in which the circulatory system has been ansformed to a system of Cartesian co-ordinates. The particles enter at T as before and describe sinusoidal paths, which for a fixed phase at entry, have the same nodal points. With the assumption of circular symmetry, the ordinate y represents the instantaneous distance of a particle from the inner wall of the vacuum box, if the magnetic field had kept for that particle the same value as at the time of entry. In the presence of a magnetic field with a constant time rate of rise the inner wall of the circular vacuum chamber is represented by a line of positive slope through the origin. For a beam of zero width the trajectories are of the form

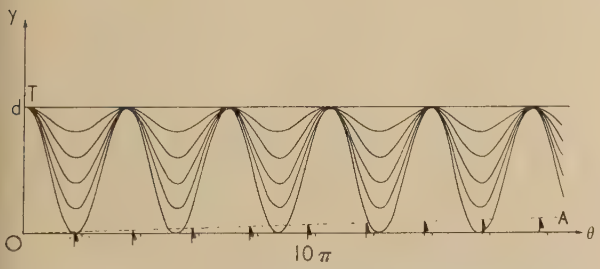


Fig. 3. Beam trajectories using Cartesian co-ordinates

The dotted line OA represents the equation $y = (\theta/2\pi)\Delta r$.

$$y = d + t\dot{r}(\cos k\theta - 1) \qquad (4)$$

where d is the radial difference between T and the tip of P_I, t the time of passing T measured from $t_s = 0$, k is the ratio between the horizontal betatron frequency and the frequency of revolution and θ is the angular position. In Fig. 3 the tip of P_I appears as the function $f(\theta)$ which for integral values of l in $\theta = 2l\pi + c$ has the value $\theta\Delta r/2\pi$ and vanishes elsewhere. For reasons already discussed c is chosen here to be $\pi(1-n)^{-\frac{1}{2}}$.

It can be seen at once from Fig. 3 that particles will continue to arrive at the probe until $f(\theta) > d$, i.e. until those particles with negligible betatron oscillation have circulated for an approximate time $d/\dot{r}$. The first particles arrive at P_I at a time such that

$$t = [d - (c\Delta r/2)]/2\dot{r} \qquad (5)$$

so that at the commencement of the signal from P_I the particles with negligible betatron oscillations are very nearly half-way across the vacuum box.

At a particular position θ of a wide probe all trajectories are intercepted which pass T later than t, defined by

$$d + t\dot{r}(\cos k\theta - 1) = f(\theta) \qquad (6)$$

It is obvious that particles are only "collected" for particular values of θ. The number collected at a certain value, θ_2 say, comprises those which have trajectories which pass through the probe position at θ_2 without having previously intercepted any other probe position. If the previous collection position was θ_1 then the number of particles collected after travelling θ_2 is $N(t_2 - t_1)$ where t_1 and t_2 are the times of passing T of the trajectories which pass through the tip of P_I at θ_1 and θ_2, and N is the number of protons passing T per second.

To estimate the instantaneous current to P_I we first note that the equivalent time interval between the probe appearing at θ_1 and θ_2 in Fig. 3 is $(\theta_2 - \theta_1)\Delta r/4\dot{r}\pi$. Then from

$$t = \left\{[l + (c/2\pi)]\Delta r - d\right\}/\dot{r}[\cos k(2l\pi + c) - 1] \qquad (7)$$

the probe current for the position or time associated with a significant value of l is

$$I(\theta) = 4\pi\dot{r}N(t_2 - t_1)/(\theta_2 - \theta_1)\Delta r \qquad (8)$$

except for $l = 0$. For this position, which is responsible for the main spike, $I(\theta) \doteq N$ and the total current from P_I for $l = 0$ is equal to the injected current together with the value of $I(\theta)$ given by $\theta_1 = c$. It is easy to see that for the case of a beam of zero width the average value of $I(\theta)$ must be very close to N. A plot of $I(\theta)$, for a probe of width 2 cm on the inner wall of the vacuum box and theoretical constants appropriate to this machine, is shown in Fig. 4. It is not difficult to extend this analysis to the case of a beam of density N particles per unit width per second and of width w entering at T. Each elemental width Δw gives a signal of form of $I(\theta)$ but displaced in time, since the particles have to travel in the y direction a distance different from d. The trajectory entering at $d-w$ has the same amplitude of oscillation as a trajectory entering at d at an interval $w/\dot{r}$ earlier, and it also takes $w/\dot{r}$ less time to reach a corresponding probe position. The probe current function for this particular trajectory is $[I(\theta - 4\pi w)]/\Delta r$. Thus if $P(\theta)$ is the probe current function for a beam of finite width

$$P(\theta) = \int_0^W I(\theta - 4\pi w)/\Delta r \, dw \qquad (9)$$

where w is the maximum width of beam which enters at a time t and can circulate around the machine. It is not proposed to consider the expression for $P(\theta)$ in detail but it will be noticed that $P(\theta)$ will have the same general form as $I(\theta)$ but that for a constant w the sharp steps will be made to slope over an interval of $\theta = 4\pi w/\Delta r$. Much useful information about the nature of the injection process can be obtained from a simple analysis of $P(\theta)$.

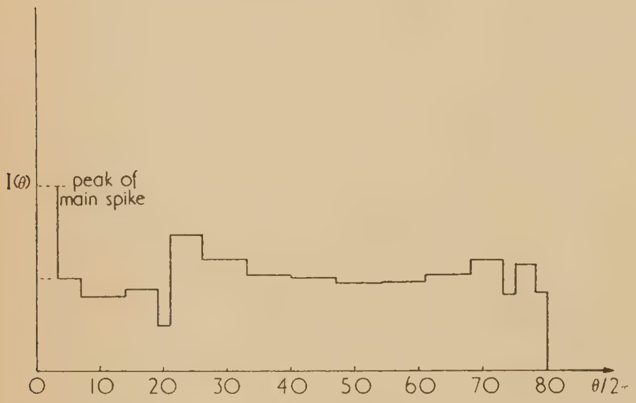


Fig. 4. Theoretical histogram of probe current

In the presence of the radio-frequency acceleration, gated at the peak of the main spike, the signal from the spiralling beam is replaced by a complex pattern owing to those particles which strike P_I because of an excessive amplitude of oscillation.

When the machine is in actual operation the beam is not necessarily injected through the guide plates into the vacuum box in a perfectly tangential manner, since a direction is found empirically for which an optimum amount of spiralling beam is accelerated by the radio-frequency system. It is found that this condition corresponds closely with the appearance of a maximum spiralling beam in the signal P_I with no radio-frequency so that this criterion is used for alinement. However, only those particles which execute very small betatron oscillations are acceptable for the radio-frequency acceleration.

THE RISING VOLTAGE EQUIPMENT

It has long been appreciated in synchrotron theory that, for a given injection current, some improvement could be obtained in the accelerated beam if the horizontal oscillations at injection were removed by matching the injection energy to the magnetic field. A practical method for raising the injection energy was proposed some years ago by H. Le Caine,(2) before any injection apparatus existed for this machine. The present rising energy equipment is basically the same as his original design.

It might be assumed that the freedom from energy stabilization, so carefully sought for normal injection, would be if an attempt was made to use a rising energy equipment. perfect precision was essential this assumption would be t but in practice it is found that the equipment may be u without losing any useful degree of absolute stabilization.

In Fig. 1 it can be observed that for particles of a gi e/m the energy appropriate to the instantaneous mean o through T, at a radius r, is

$$E = \frac{er^2B_0^2}{2\mathrm{m}}\left(\frac{r_0}{r}\right)^{2n}$$

so that the time rate of rise of the injection energy necess to maintain the mean orbit of an injected particle at T

$$\dot{E} = \left(\frac{2Ee}{m}\right)^{\frac{1}{2}} r\dot{B}_0\left(\frac{r_0}{r}\right)^n$$

Since $\dot{B}_0$ is constant at any useful injection energy we see t $\dot{E} \propto E^{\frac{1}{2}}$. In practice the range in E is not great so that i adequate to apply a fixed $\dot{E}$ provided two restrictions observed. It is obviously important that the rising ene should be applied at the correct time, namely when the m orbit for the injection energy shrinks past T. This requi ment is met by triggering the rising energy from a suita delayed signal obtained from the trailing edge of the pu from P_0. It is also important that the time rate of rise the energy must not exceed the value of $\dot{E}$ given above, else injection becomes impossible. The variation accelerated beam with values of the rate of rise slightly l than $\dot{E}$ is not very marked, so that the choice of such a va of $\dot{E}$ gives reliable operation, which for practical purposes independent of the absolute value of E. For correc initiated rates of rise approaching $\dot{E}$ there is a wide inter of time over which the radio-frequency acceleration m commence, without any variation in accelerated beam.

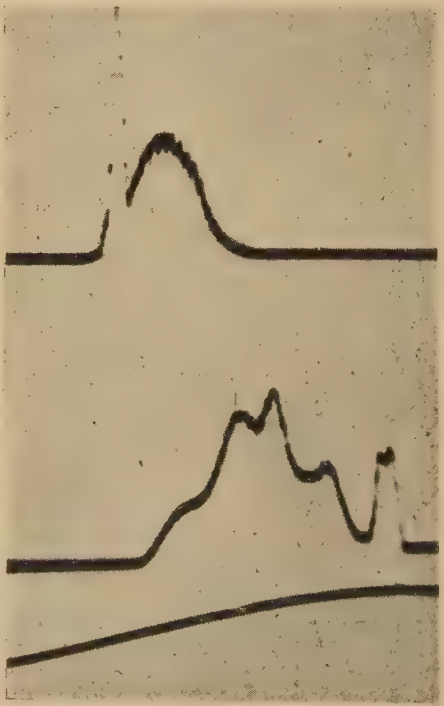


Fig. 5. Oscillograph photograph of probe signal with and without rising voltage (lower curve represents rising voltage)

inciple it is easy to see this, because for correctly applied nditions of rising energy the vacuum box remains filled ntinuously with spiralling beam, free from horizontal cillations. For as long as this condition persists the nount of beam captured by the radio-frequency acceleration independent of the choice of the instant of initiation. This a useful result for it is possible in this machine to apply $\dot{E}$ r about 500 μs.

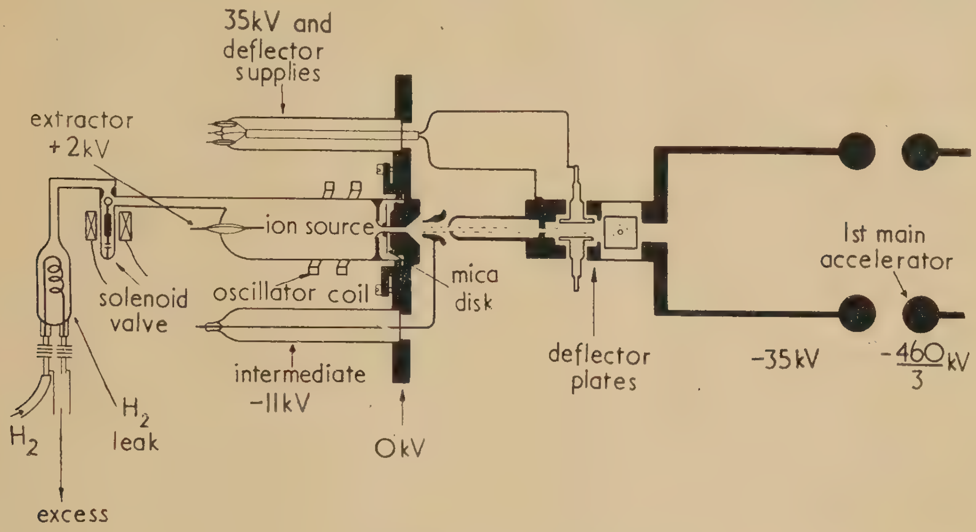


Fig. 6. Ion source and auxiliary equipment

For comparison an oscillograph record of the normal nal from P_I and the signal with a time rate of rise in ergy is shown in Fig. 5. No radio-frequency acceleration s present and it will be seen that during the application of rising energy no main spike is present as the responsible bit cannot occur. The time over which the spiralling beam rives at P_I is increased. It can be seen that the time rate rise of the energy was not constant in the particular case osen, and when it fell towards the end of the application nain spike was possible. Quantitative results will be given a subsequent paper.(1)

THE ACCELERATOR TUBE

In order to reduce the effort required for the injection paratus it was decided in early considerations of machine licy, before the author was connected with the synchrotron oject, that tangential injection should be made from a nventional type of accelerator tube. No attempt was to be ide to reduce the normal high voltage clearances required free air, which decision has meant that the ion source for accelerator tube is about fourteen feet from the entrance the guide plates. A Mumetal cone has been used to ovide magnetic shielding over the path of the beam from last lens electrode to the guide plates. Since the aperture the entrance to the machine is about 0·30 × 0·38 in., nement problems are important, particularly in view of the mparatively low energy of 460 keV.

A radio-frequency type of ion source is used with a very nple containing vessel (Fig. 6) and a compact self-excited cillator, the tank coil of which surrounds the discharge e. Ions are extracted from the discharge by means of a sitive pulse of about 2 kV applied between the extractor ctrode and the annulus on the end of the aluminium canal, ich just protrudes above a large mica disk. The annulus looks into an aperture of diameter about 0·5 in. in the discharge vessel. The exit of the canal terminates in a cone and cylinder type of condenser lens (Fig. 7) which has been found from previous experience to be efficient for converging the extracted ions. Typical rays and equipotentials for such a lens, obtained by approximate methods and neglecting space charge, are shown in Fig. 7. In practice the modification of the lens of Fig. 7 as shown in Fig. 6 makes little difference to the performance.

Because of the alinement problems, particularly the necessity of aiming the beam centrally down the Mumetal cone, which is only 0·75 in. in diameter at the exit, provision is made for electrostatic deflexion of the beam near to the ion source. A region of "necking" of the beam was placed in the vicinity of the electrostatic deflector plates. This general type of structure, with adequate stops, has the advantage of preventing excited neutral atoms and molecules from the discharge striking the tube electrodes and causing unwanted electron currents, which encourage tube breakdown and reduce the service life.

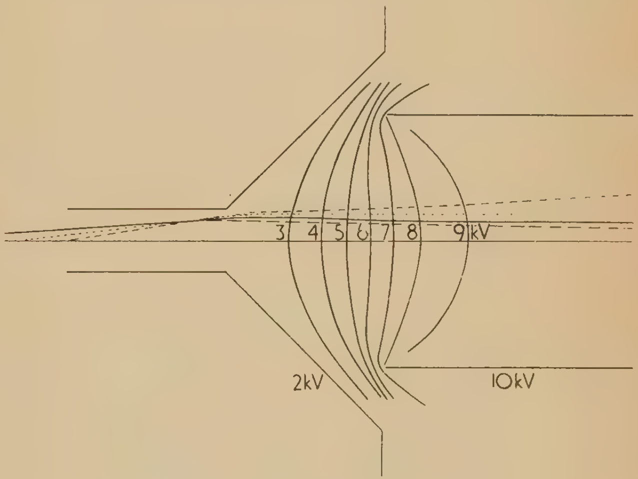


Fig. 7. Focusing lens system

The beam enters the field free region within the Mumetal cone after acceleration by the main high voltage lenses, which form a positive system as shown in Fig. 8. Variation of the final convergence is controlled by the initial focusing conditions, i.e. by the location of the region of necking. Under favourable circumstances a direct beam of protons of about 700 μA has been measured on the probe at *I*, which is effectively about 100 ft from the ion source.

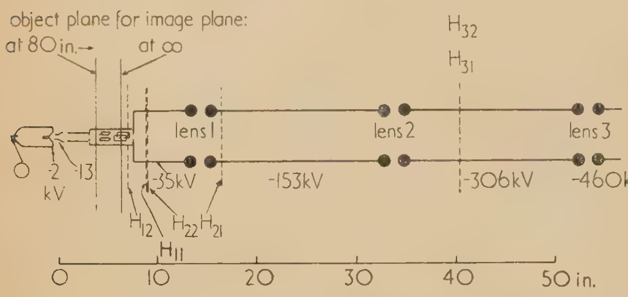


Fig. 8. Main accelerating lens system

On account of the proximity of the ion source to the synchrotron magnet the discharge is extinguished by the stray magnetic field near the peak of each cycle. The phenomenon, advantageous from the aspect of the duty cycle of the ion source and oscillator, necessitates the provision of some means of restriking the discharge, since under the best operating conditions the ion source is not self striking. A solenoid valve (Fig. 6) in the low pressure hydrogen line, between the nickel tube leak and the discharge vessel, is closed whenever the discharge fails. After about seven seconds the valve is opened and, if no discharge ensues in the burst of gas, the closing of the valve is repeated automatically. Under normal operating conditions the gas surge is adequate to cause reliable striking of the discharge, provided the focusing potentials are applied to the various lens electrodes. As there is no useful purpose to be achieved by operating the discharge in the absence of the focusing potentials, the precise relationship between the electrostatic field due to their presence, and the striking of the discharge in the ion source has not been investigated. When the discharge is on, the control circuit keeps the solenoid valve open.

The mechanical support of the accelerator tube is such that all useful angles of approach to the guide plates may be explored.

THE ACCELERATOR TUBE CONTROLS AND SUPPLIES

It is proposed to give only a very brief description of the high voltage controls for the accelerator tube. These, together with a source of power, which consists of a belt-driven rotary convertor which generates both alternating and direct current, are contained in an aluminium shield supported on a Paxolin cylinder (made by the Micanite and Insulating Co. Ltd.).

The extractor pulse unit. The signal which triggers the extractor pulse is obtained primarily from a peaking strip unit situated in the magnetic field of the synchrotron. About 200 μs before injection would be possible, a signal is obtained which excites a 46 Mc/s transmitter. This is coupled by means of a pair of large inductive loops to a simple receiver in the control dome. The receiver in turn triggers a circuit which switches a charged condenser to the extractor electrode and thus provides a proton beam in the accelerator tube. Adequate precautions are taken to prevent continu extraction under any circumstances.

The ion source oscillator. A compact self-excited oscill of about 14 Mc/s and utilizing four type 807 tubes in par push-pull, excites the ion source. The diameter of the turn tank circuit has been adjusted experimentally to gi good match into the discharge tube at the operating press The solenoid valve is controlled by a circuit which respo to the power consumption of the oscillator unit in such a that a light load on the power supply brings into opera an oscillating relay circuit which opens and shuts the va When the power supply load is heavy, which is a conseque of a suitable discharge being maintained in the ion sou the valve is made to remain open.

The high voltage supply for initial focusing. A casc generator using selenium rectifiers supplies the 35 necessary for the initial acceleration of the extracted be the potential for the cone and cylinder lens coming fro voltage divider with an adequate storage capacitor. the mean potential of the deflector plates is the same as last electrode in the initial focusing system, an isolated su with step switch potentiometer control is used to provide deflecting fields.

Auxiliary supplies. The hydrogen leak, which is electrically heated spiral of nickel tube down which a cur of hydrogen is passed, is electrically interlocked wit cooling fan and the ion source oscillator so that overhea of the end of the accelerator tube cannot occur. For s plicity the hydrogen is generated in an electrolytic cel ground potential and taken to the leak through a plastic tu Under normal circumstances this supply is not interru so that air cannot enter the system and cause condensa troubles at the waste exit from the leak.

The main high voltage circuit. A commercial high vol cascade generator provides an output of about 460 kV wh is stabilized to about ±1% by means of a primary cir regulator designed by H. Le Caine. For reasons alre discussed the stability is not essential with the normal sys of injection, but the regulator is convenient and has a benef effect on the overall performance of the high voltage genera owing to the waveform which it produces at the input to high voltage transformer.

For the operation of the rising voltage equipment i essential that the high voltage generator should pres either a constant, or, and more preferably, a very h

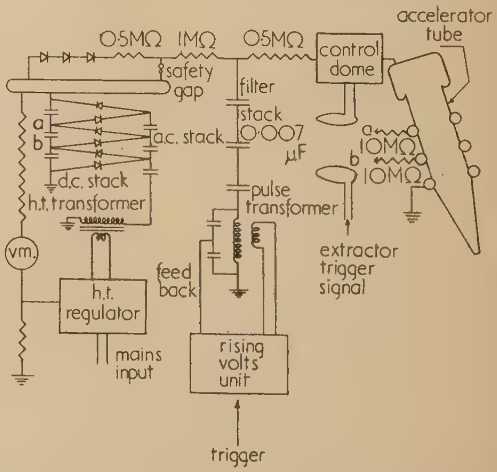


Fig. 9. Block diagram of h.t. supply and controls

vm. = voltmeter 0–500 kV.

pedance to applied positive pulses. Under normal con- ions this impedance depends on the timing of the pulse h respect to the conduction cycle of the rectifiers. To ke the output impedance infinite a suitably protected, ies selenium rectifier (Fig. 9) has been inserted between the herator and the source of pulses. This rectifier has the ditional advantage of removing the ripple component m the high voltage supply, since between duty pulses the er condenser is recharged to the peak output voltage.

The voltage distribution on the three sections of the celerator tube is obtained by connexions, in the form of ter resistances, to appropriate points on the d.c. stack of high voltage set.

CONTROL AND MONITORING CIRCUITS AT GROUND POTENTIAL

Amplifying, mixing, differentiating and discriminating cuits for three probes in the vacuum box are provided. By ans of two double-beam oscilloscopes and patch boards of axial plugs any reasonable monitoring circuit can be ranged in a few seconds. The radio-frequency control om can provide acceleration for any period after the currence of the main spike; consequently the conditions optimum injection and radio-frequency pick-up can be idied experimentally. For example it is easy, by means the signals from P_I, to study the collapse after radio-quency switch-off of particles which have been accelerated various times. Shortly before each injection pulse all obe amplifier valve heaters are switched off in order to luce the noise level.

A means is provided for modulating the power supply for guide electrodes so that the injected beam may be inter-pted or "marked." Saw-tooth modulation can also be posed on the guide field, with or without marking, so that experimental determination of the most useful part of the injected beam may be made. The actual current flowing to each electrode of the guide plates can be monitored, and it is found that this current can be as much as tens of milliamperes during injection, probably due to secondary emission from the plates.

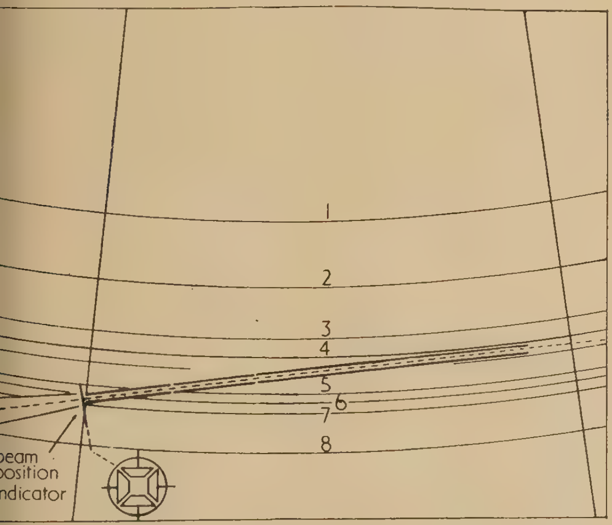


Fig. 10. Variation of magnetic field near guide electrodes

	R (cm)	*Bz (relative)*
Curve 1	434	102
2	450	100
3	462·5	99
4	470	97·5
5	476	90
6	478	80
7	480	70
8	490	40

A permanent display of the distribution of the beam at the entrance to the guide plates is made by monitoring the charge collected on each of four molybdenum fingers surrounding the aperture (Fig. 10). In addition a current collector may be placed in front of the guide plate aperture and the beam intensity displayed so that the accelerator tube performance can be examined.

THE GUIDE ELECTRODES

The guide electrodes permit a near tangential approach of the trajectory out of the Mumetal cone into a region of magnetic field of suitable *n*-value. As can be seen in Fig. 10, the magnetic field is about 25% greater at the tip of the guide electrodes than at the entrance, and in order to keep an almost straight trajectory, without the complication of a variable guide electrode spacing, the electrodes are divided into three sections. In this way, by adjusting the electric field in each section to cancel the deflexion produced by the mean magnetic field over the section, it is possible to keep the effective aperture between the electrodes very near to the geometrical aperture.

The electrodes are contained as a unit in an earthed stainless steel tube so that only the innermost end plate is exposed to the circulating beam. Thus if this plate is at earth potential, no stray electrostatic field penetrates far into the vacuum box. Empirically it has been found that a slight increase in circulating beam occurs if the innermost end electrode is not quite at earth potential. It was at first thought possible that a more elaborate shaping of the electrostatic field by using non-planar electrodes might be necessary, but in practice this has not been required, for no aberration of the beam in the vacuum box has been attributed to the simplicity of the electrodes.

It would seem useful for the future to investigate the possibility of using guide electrodes with transparent tips in the form of a grid of fine wires instead of a pair of plates. With a compensating grid behind the normal outer electrode it would be possible for most circulating protons to make an undeviated passage through the guide electrodes and thus diminish the loss due to collisions with the inner electrode.

THE INJECTION CYCLE

In order to summarize the functions of the various components it is proposed to summarize the cycle of events connected with the injection equipment.

Immediately after an injection pulse the ion source discharge is extinguished owing to the stray magnetic field. This causes the solenoid valve-closing circuit to operate and the gas pressure in the hydrogen leak to rise. About 1 s before the synchrotron magnet circuit is closed the solenoid opens and the surge of gas initiates the discharge.

About 0·5 s later the heater circuit of the probe amplifiers is broken and the current for the peaking strip bias coil is switched on for 1 s. After about 10 ms from the closing of the magnet circuit a signal from the peaking strip unit is transmitted *via* the coupling loops to the extractor gate, which allows a proton beam to pass down into the guide plates for some milliseconds. During this time injection occurs.

The detection of injection is normally by means of the observation of the main spike from P_I, which is used as a gating signal for the radio-frequency control room. Alternatively a delayed signal from P_0 is provided. A pulse obtained from differentiation of the fall of signal from P_0 is used for triggering the injection monitoring oscilloscopes, since this makes the display independent of energy drifts. Provided that injection can occur while the extractor is gated, the whole procedure is automatic.

ACKNOWLEDGEMENTS

The author gratefully acknowledges assistance from Profs. M. L. Oliphant and P. B. Moon under whose general direction he has worked. Individual acknowledgements are made to: D. G. Marshall for his part in the early planning of the equipment, H. le Caine for the initial development of the high voltage regulator and rising energy equipment, W. E. Burcham, P. Barrett and D. F. Bracher for the peaking strip equipment, D. F. Bracher for the provision of a sw frequency generator for early tests of radio-freque acceleration, L. Riddiford, R. F. Coe and A. E. Souch assistance with vacuum equipment, J. L. Symonds for study of a Thoneman type ion source, B. Ledley and Livesey for the 46 Mc/s transmitter and S. Brunt mechanical assistance.

Finally, a particular acknowledgement is made to author's colleagues, R. F. Coe and T. B. Vaughan, for t invaluable help in the operation of the injection appara and the analysis of the phenomena.

REFERENCES

(1) Ramm, C. A., Coe, R. F. and Vaughan, T. B. *J.* *Instrum.* To be published (1956).

(2) Le Caine, H., Ph.D. Thesis (University of Birmingh 1952).

An isothermal micro-calorimeter

By J. B. Stott, B.Sc., Ph.D., School of Mines, University of Otago, Dunedin, New Zealand

[*Paper received* 22 *August*, 1955]

A calorimeter is described which, although nearly isothermal and independent of the specific heats of the materials employed, can still be used over a wide range of temperatures and makes use of a bank of thermocouples to measure the heat evolved. An attempt is made to obtain the maximum theoretical sensitivity by making most of the heat produced pass down the thermocouples. The high rate of heat transfer down the thermocouple wires has made it possible to pass up to 15 ml./min of air through the calorimeter without affecting the sensitivity.

The apparatus described below was developed from a differential thermal analysis apparatus which the author has used to measure the amount of heat generated by oxidizing coal.(1) In the latter apparatus any rise in temperature in a small amount of coal is measured by one junction of a differential thermocouple, the other being embedded in an inert material. With this arrangement a given amount of heat produced in the coal produces a varying thermocouple voltage. It was found that the integral of this voltage with respect to time was a reasonably good measure of the heat produced. Moreover, the apparatus appeared sensitive enough to measure the rate of heat evolution caused by oxidation of the coal, even at temperatures about 50° C, and also was able to measure the amount of heat absorbed as moisture was driven from the coal. Both of these two quantities of heat are very important in the spontaneous heating of coal. Unfortunately, this type of apparatus is somewhat crude and it is difficult to treat the heat transfers which take place theoretically. The apparatus was designed to dissipate quickly any heat which is produced, mostly into a nickel block, but some of the heat also passes down the thermocouple from the hot junction to the cold. The amount of heat which passes between the hot and cold junctions for a given temperature rise is easily calculated from the thermal conductivity of the thermocouple materials and was found to be about 3% of the total heat evolved. The author was interested in the possibility of designing an apparatus in which the majority of the heat produced could be made to pass down the measuring thermocouple or thermocouples.

A thermocouple will best measure a given rate of heat production when all the heat produced is made to pass down the thermocouple wires. This was pointed out many ye ago by Lord Kelvin(2) who also showed that it was usuall very inefficient means of transferring heat into electri energy. In the apparatus described below, a heat flow 1 cal/s is converted into electrical energy, equivalent to ab 3×10^{-8} cal/s. A similar principle has also been used Hatfield and Wilkins(3) who utilized a sandwich of silver/ lurium alloy between disks of copper to measure heat trans through the walls of a room. The application of this princi to micro-calorimetry is discussed below.

THEORY OF THE CALORIMETER

The theory of the use of thermocouples in micro-calc metry has been very fully discussed by Whipp(4) and ma of the following equations are exactly analogous to the or which he put forward. However, the treatment of thermocouple as a means of measuring heat rather th temperature leads to certain important modifications. It usual to measure the electromotive force of thermocouples a calorimeter by a galvanometer(4, 5) and the equation defin the sensitivity of a calorimeter can then be derived as follo The heat flowing down the thermocouple wires for a tempe ture difference $\Delta\theta$ between the hot and cold junctions is:

$$Q = (n/l)(k_1 a + k_2 z a)\Delta\theta$$

where Q is the heat flow (cal/s), n is the number of coupl a is the area of the copper wire, za is the area of the constant wire, l is the length of each couple wire, k_1 is the therm conductivity of the copper, and k_2 is the thermal conductiv of the constantan.

Now the electrical resistance of these couples will be:

$$R = nl[(r_1/a) + (r_2/za)] \tag{2}$$

here r_1 is the electrical resistivity of the copper wire and is the electrical resistivity of the constantan wire.

The voltage developed by the thermocouples will be:

$$V = nc\Delta\theta \tag{3}$$

here c is the thermal e.m.f./°C of the thermocouple.

For galvanometers of the same type an approximate lationship between the galvanometer resistance and the nsitivity is(6):

$$D = G\surd(R_G)I \tag{4}$$

here G is the galvanometer constant, R_G is the galvanometer sistance, and I is the current passing through the galvanoeter;

so

$$V = (R + R_G)I \tag{5}$$

ombining these equations we find that the sensitivity S, efined as the deflexion produced by unit flow of heat, is:

$$= D/Q = nCG\surd R_G \Big/ \left\{H\left[R_G + \frac{n^2}{H}(k_1 + zk_2)\left(r_1 + \frac{r_2}{z}\right)\right]\right\} \tag{6}$$

here H is a fundamental property of the calorimeter defined y equation (1), namely, the heat transfer coefficient of the ermocouple wires. (It is assumed that the heat transformed to electrical energy is negligible.)

e.

$$H = Q/\Delta\theta = (na/l)(k_1 + zk_2) \tag{7}$$

fow for a given value of H and R_G it can be proved that the nsitivity of the calorimeter is a maximum when:

$$n^2 = R_G H \Big/ (k_1 + zk_2)\left(r_1 + \frac{r_2}{z}\right) \tag{8}$$

nd hence that $R_G = R$ for maximum sensitivity.

These equations enable a calorimeter to be designed of aximum sensitivity to suit a given galvanometer, if the esired heat transfer coefficient of the thermocouple wires is nown. It is possible to show that a thermocouple will have aximum sensitivity to heat flow when about equal amounts f heat flow down each of the wires(4) and the cross-sectional rea of the wires can be adjusted to this end. In order to btain this condition:

$$a/za = \surd(K_2 r_1/K_1 r_2) \tag{9}$$

nd this defines z, which is about 1/22 for copper/constantan.

THE HEAT TRANSFER COEFFICIENT OF THE THERMOCOUPLE WIRES

Several factors influence the choice of the heat transfer oefficient H. First of all it follows from equation (6) that e bigger H is the smaller the sensitivity to heat flow. On e other hand, if a small amount of heat is released quickly the apparatus, it will be shown later that the bigger H is, e bigger will be the *transient* deflexion of the galvanometer.

Probably a more important consideration is the effect of gas flowing through the calorimeter. A high heat transfer oefficient means that a low temperature difference exists etween the hot junctions and the cold junctions. Any gas owing through the hot reacting material will leave the lorimeter roughly at the temperature of the hot junctions. The lower this temperature, the less heat is carried away by the gas.

The heat carried away by a flow of air of 10 ml./min will be:

$$Q = (10/60) \times 3{\cdot}1 \times 10^{-4}\Delta\theta \text{ cal per s per °C}$$

(specific heat of air $3{\cdot}1 \times 10^{-4}$ cal per °C per ml.) or very nearly 5×10^{-5} cal per s per °C temperature difference.

It is desirable that this should be at the most 1/100th of the heat flowing down the thermocouples which will be:

$$Q = H\Delta\theta \geqslant 5 \times 10^{-5} \times 100\,\Delta\theta$$

Therefore $H \geqslant 5 \times 10^{-3}$ cal per s per °C

In the apparatus described below H was $1{\cdot}56 \times 10^{-2}$ cal per s per °C.

THE LENGTH OF THE COUPLE WIRES

One further point affects the design of the calorimeter, namely the ratio of the cross-sectional area of the couple wires to their length, the term a/l in equation (1). The value of a/l follows from the values of n and R decided by equation (8) and inserted in equation (7). It remains to be decided if there is an optimum value for l. As the ratio of a/l is fixed, any increase in l must be accompanied by a similar increase in a (a thermocouple of length 1 cm would mean using copper wire of about 36 s.w.g. in a calorimeter described below).

It has previously been assumed that all the heat which enters the couple at the hot junction flows out from the cold junction. This is not strictly true, as the surface of the wire always loses some heat to the surroundings at a lower temperature; the longer the wire, the greater the loss.

For 36 s.w.g. copper wire, $r = 9{\cdot}7 \times 10^{-3}$ cm and K (copper) $= 0{\cdot}92$ c.g.s. units. When the heat loss is purely by black-body radiation from a surface of 100% emissivity, for small temperature differences $k = 5{\cdot}44 \times 10^{-12}$ c.g.s. units; and we find that a 36 s.w.g. copper wire could be about 1500 cm long before losing more than 0·2% of the heat flowing into the wire. For a constantan wire, of a sufficient radius to carry the same amount of heat/unit temperature difference, similar conditions obtain and a length of about 1000 cm is permissible.

Under conditions of natural convection, with a heat transfer coefficient of about 10^{-5} c.g.s. units, a length of 0·5 cm would be sufficient to lose about 3% of the heat flowing down a copper wire. Hence, unless the atmosphere around the couples can be evacuated, it is desirable to keep the couples fairly short.

UNSTEADY HEAT FLOW

It may be argued that when conditions are not steady and the temperature of the hot junction is rising fairly rapidly, the normal "steady state" conductivity equation does not apply. An investigation has therefore been made of the effect of these unsteady conditions on the heat flow as measured by the temperature of the thermocouple wire.

A solution of the following problem leads to an estimate of the amount of error introduced by unsteady heat flow. A rod of length l is bounded by two parallel planes. One end is kept at the initial temperature, which is constant throughout the rod at $t = 0$, and the other end is raised at a constant rate of $k°$ C/s. The temperature across any cross-section of the rod as assumed to be constant with no heat transfer at the surface.

It is desired to know the heat flowing into the hot end of the rod at any time and for this we need $(d\theta/dx)_{x=0}$. The solution to this problem is:

$$\left(\frac{d\theta}{dx}\right)_{x=0} = -\frac{kt}{l} - \frac{kl}{3D} + \frac{2kl}{D\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp^{-(D\pi^2tn^2/l^2)} \quad (10)$$

where D = thermal diffusivity, D copper = 1·02 c.g.s. units, and D constantan = 0·055 c.g.s. units, and this leads to the following conclusions.

If the hot junction of a copper constantan thermocouple, length 1·8 cm, is raised at a steady rate, the heat flowing into the hot junction 100 s after the start of the temperature rise exceeds by 2–3% the heat flow indicated by the temperature of the hot junction, assuming a constant temperature gradient along the thermocouple wires. Making the same assumption, it can also be shown by integrating equation (10) that an estimate of the total heat flow in the first 100 s will be in error by about 5%. After a longer time the error becomes proportionately less, so that after 500 s the error in the estimated heat flow will be about 1%. As the temperature of the hot junction drops at the end of the experiment, there will be some tendency for the reverse effect to take place, i.e. the heat flow at the hot junction will be less than the heat flow indicated by the temperature of the hot junction. In an experiment taking 15 min or longer and giving a heat flow-time graph similar to those shown in Fig. 5, it will be seen that the estimate of the total heat flow will not be in error by more than 1% after the first five minutes of the experiment. The percentage deviation of the heat flow from that indicated by the thermocouples at a given time is independent of the rate of rise of temperature and also, of course, of the thickness of the wire.

This useful result is to some extent due to the small amount of heat flowing down the constantan wire in the present apparatus, for the low diffusivity of constantan makes the temperature gradient along the wire depart appreciably from linearity. For instance, for a constantan wire the deviation of indicated, from true, heat flow even after 100 s is still 20% and only approaches 1% in 2000 s. It appears from this that if the constantan wire is made thick enough to carry half the heat flow, the deviation of the heat flow, as measured by the temperature of the hot junction, from the actual heat flowing into the junction might be considerable. This should therefore be borne in mind when making use of equation (9) to decide the relative thickness of the couple wires.

CALORIMETER DESIGN

The above considerations have been applied to the design of the calorimeter. If a large amount of the heat developed is to pass quickly down the thermocouple wires, it is desirable that they should be in very intimate contact with the material producing the heat. Also, when the heat has travelled to the cold junctions it must be dissipated into a fairly large heat sink. If the heat capacity surrounding the cold junctions is 100 times the heat capacity of the material emitting the heat and the hot junctions, then about 99% of the heat produced will flow into the cold sink, giving conditions approximating closely to an isothermal calorimeter. It was found easy to ensure this, and in the apparatus described below the heat capacity of the cold sink was about 1000 times greater than that of the reactants and the hot junctions. The design of the apparatus is shown in Figs. 1, 2 and 3. It was apparent that there would be ample sensitivity for the present purpose and so the design was influenced largely by the materials which were immediately available.

The couples themselves, of which there were 100, were m from 36 s.w.g. copper and constantan wire. The hot junct were formed by twisting together sufficient wire to gi

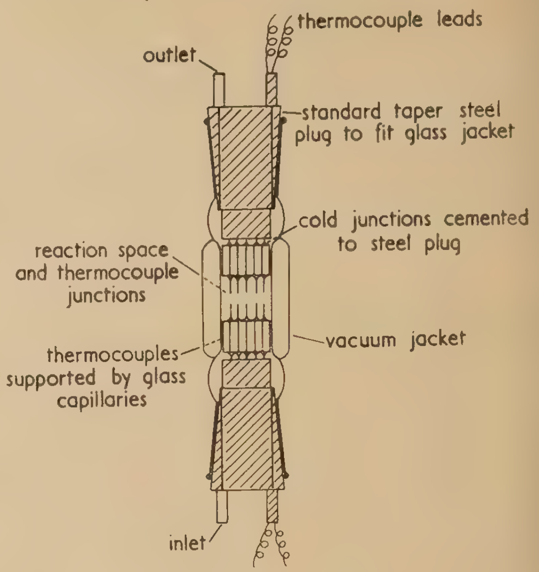

thermocouple leads
outlet
standard taper steel plug to fit glass jacket
cold junctions cemented to steel plug
reaction space and thermocouple junctions
vacuum jacket
thermocouples supported by glass capillaries
inlet

Fig. 1. Design of micro-calorimeter

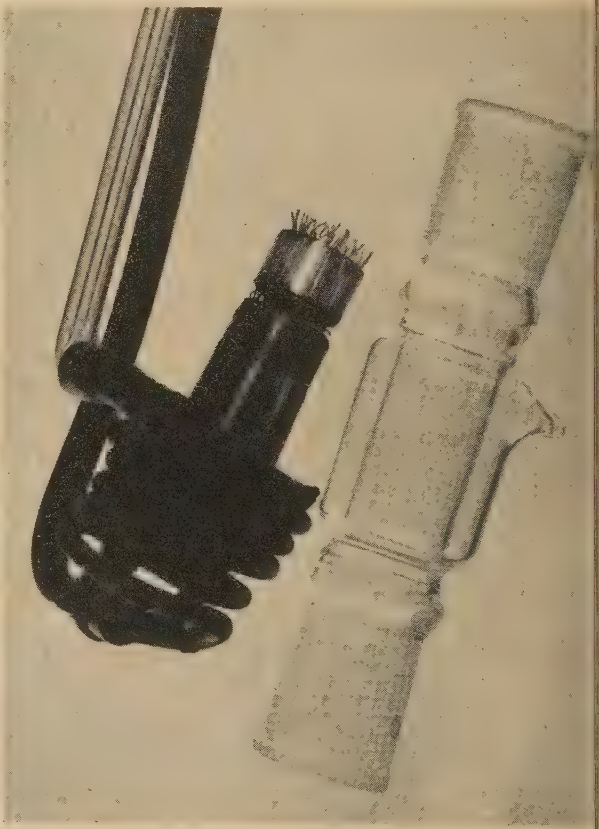


Fig. 2. Vacuum jacket and bottom thermocouples

length of 1 cm and this was hard soldered. This lengt wire projected into the coal in the reaction chamber wh would hold about 3 g of loosely packed coal, equivalen a heat capacity of 1 cal/° C. The length of the couple w oper was 1·8 cm and the cold junctions were again hard ldered, only about 2 mm length of wire actually being isted together and this was cemented with shellac to a steel ug ground to fit a standard B24 socket. Fifty couples were ldered in series and cemented to each of two steel plugs d each wire was supported and insulated by being pushed rough a length of glass capillary. This capillary support as made by packing a short length of glass tubing, which ould fit closely inside the vacuum jacket, with a large number f capillary tubes until a tight fit was obtained and then the hole was annealed carefully so that the capillaries adhered one another without being distorted in shape.

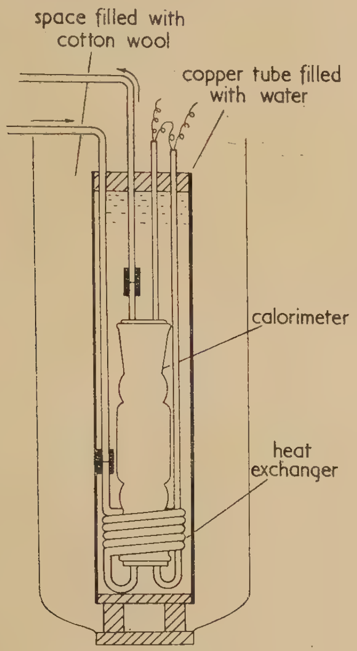


Fig. 3. Thermal isolation of calorimeter

The vacuum jacket was designed to prevent, as far as ossible, the radial flow of heat away from the junctions. It desirable to make the inside cylinder of glass as thin-walled s possible to restrict the flow of heat parallel to the length f the calorimeter. When in use the calorimeter was contained nside a length of copper tubing 25 cm long by 6·5 cm in iameter and with a wall thickness of 4 mm. This was filled ith water and sealed at both ends by rubber bungs, the lectrical leads and tubing being brought out through one end. he copper tube was placed inside a large glass vessel and as packed round with cotton wool, the whole being conained in an ordinary thermostated water bath, the temperaure of which was controlled to within about 0·02° C. This rrangement was found to be very satisfactory and no uctuations due to temperature drifts and changes could be etected even though the apparatus might be left going for everal days.

CALIBRATION OF THE APPARATUS

In use gas would be continually flowing through the pparatus and it was desirable to calibrate it under similar onditions. In the first set of calibrations the heat produced vhen water vapour reacts with quick lime was measured. Quick lime was contained in the apparatus in contact with he thermocouples whilst water vapour was passed through in a stream of air. In the first method a drop of water of known weight was introduced into the air stream and as it evaporated it was carried forward into the apparatus, the deflexion of the galvanometer being measured over the period of the experiment. Any water which came through the apparatus was collected in a drying train and weighed.

In the second method dry air was passed through a solution of potassium chloride in water and became saturated at the vapour pressure of this solution. The air was then carried through the apparatus in the usual way and any unreacted moisture collected at the outlet. The rate of heat production in the calorimeter could be varied by varying the flow of air and steady galvanometer readings were taken up to air flows of 25 ml./min. The results of these two experiments are shown in Tables 1 and 2. They demonstrate that the apparatus is equally sensitive to constant and varying rates of heat

Table 1. *Calibration of first apparatus by method* 1

Heat produced by a known weight of water (cal)	*Area of deflexion* (mm × h)	*Average deflexion per unit rate of heat release* (mm per cal per h)
22·6	35·3	1·56
6·5	9·0	1·39
12·2	18·0	1·48
171·4	253·4	1·48

Table 2. *Calibration of first apparatus by method* 2

Rate of heat release (cal/h)	*Galvanometer deflexion* (mm)	*Rate of air flow* (ml/min)
67·3	82·2	24·9
67·0	86·8	24·5
51·9	73·5	17·9
42·3	61·4	14·1
33·6	48·9	11·3
32·2	47·7	11·5
26·0	35·2	10·6
24·8	33·4	10·2
22·3	33·4	10·2
14·0	21·4	5·7

Average deflexion/unit rate of heat release = 1·43 mm per cal per h.

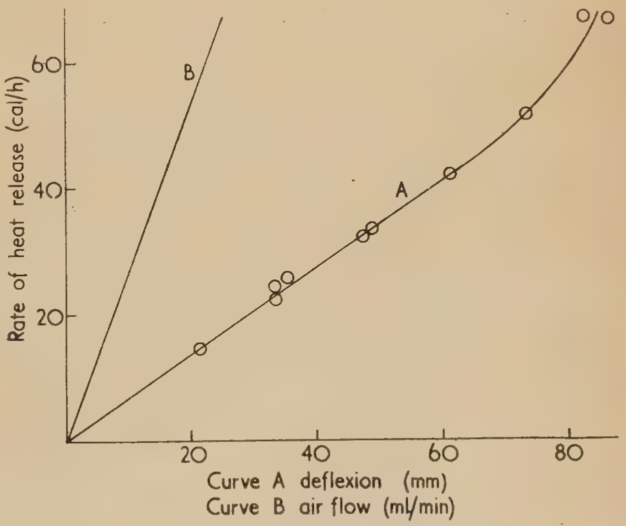


Fig. 4. Effect of air flow on sensitivity

release, within the limits described above under the heading Unsteady Heat Flow. In Fig. 4 the results from Table 2 are expressed graphically in order to show that the sensitivity is unaffected by the rate of air flow through the calorimeter up to 15 ml/min. These figures were actually obtained with an earlier apparatus differing slightly in form to the one previously described but the results are included to show the consistency between the two methods of calibration. The differences between this older apparatus and the present one were that the steel blocks were cemented to the reaction chamber with black wax, rather than being ground to fit, and also that the vacuum jacket was omitted. The results of calibrating the second apparatus are shown in Tables 3 and 4. Table 3 shows the area produced under the deflexion time graph compared with the amount of heat evolved when water reacts with quick lime. In these experiments the practice of introducing a weighed amount of water into a dry air stream was followed.

Table 3. *Calibration of second apparatus; reaction between water vapour and calcium oxide*

Heat released (cal)	*Area of deflexion* (mm/h)	*Average deflexion per unit rate of heat release* (mm per cal per h)
43·8	116·3	2·66
36·1	98·5	2·73
44·5	114·6	2·58

Table 4 shows the results obtained using the heat produced by a different reaction, namely, the oxidation of carbon monoxide to carbon dioxide by a commercial catalyst Hopcalite (made by the Mine Safety Appliance Co., Pittsburgh). In these experiments a measured volume of carbon monoxide at a known temperature and pressure was introduced into the dry air stream whilst the Hopcalite was contained in the calorimeter in the usual way. Satisfactory agreement was obtained between these two methods of calibration so that it appeared that the sensitivity of the apparatus was independent of the reactants. Two graphs of the deflexion as a function of time are shown in Fig. 5; Fig. 5(*a*) relates to the reaction of water vapour and quick lime and Fig. 5(*b*) to the oxidation of carbon monoxide.

Table 4. *Calibration of second apparatus; oxidation of carbon monoxide to carbon dioxide by Hopcalite*

Heat released (cal)	*Area of deflexion* (mm × h)	*Average deflexion per unit rate of heat release* (mm per cal per h)
0·728	1·97	2·71
0·760	2·02	2·66
0·768	2·10	2·74

DISCUSSION OF CALIBRATION RESULTS

These results can now be discussed in the light of the theory previously put forward and the theoretical sensitivity can be calculated, using the following values for the constants involved in equations (6) and (7).

k_1 (copper) $= 0{\cdot}92$ cal per °C per cm $a = 2{\cdot}43 \times 10^{-4}\,\text{cm}^2$
k_2 (constantan) $= 0{\cdot}054$ cal per °C per cm $n = 100$
$r_1 = 1{\cdot}8 \times 10^{-6}\,\Omega\,\text{cm}$ $c = 43{\cdot}3\,\mu\text{V}/°\text{C}$
$r_2 = 5{\cdot}1 \times 10^{-5}\,\Omega\,\text{cm}$ $G = 1{\cdot}57$ mm per per $\Omega^{\frac{1}{2}}$
$z = 1$ $R_G = 18{\cdot}6$
$l = 1{\cdot}82$ cm

Thus a deflexion of 10·1 mm per cal per h should have be obtained as compared with the 2·53 actually found. T was rather disappointing; although from the calibrations does not seem to have affected the reliability of the calorime in any way. It also suggests that the design may be improv considerably and the following modifications suggest the selves:

(1) the thickness of the glass forming the inside partition the vacuum jacket should be reduced as far as prac cable to prevent heat loss down its length;

(2) the capillary support for the thermocouples should replaced by a thin disk of material, as a certain p portion of the heat produced must be conducted aw down the support even when the low conductivity the glass is taken into account.

SENSITIVITY

Because of the insensitive galvanometer the sensitivit quoted here are not very large. It can be shown, howev that by using a good galvanometer a sensitivity equal to th of calorimeters of the adiabatic type are possible. If t calorimeter (with the same heat transfer coefficient) we used with a Paschen type of galvanometer of resistance 1 and the number of couples and dimensions were alter accordingly ($n = 43$) the sensitivity to heat flow would increased by about 5500 times. Sensitivity, defined deflexion/unit rate of heat flow, is not directly compara with sensitivity as usually defined for a normal calorimete i.e. deflexion/unit quantity of heat. In an adiabatic calo meter the aim is usually to produce a steady deflexion of galvanometer when a given quantity of heat is produced, t rate of decay of this deflexion being reduced to a minimu by reducing the heat transfer from the hot junctions to th thermocouples.

If a small quantity of heat is introduced quickly into th apparatus described above, a transient deflexion of the ga vanometer is obtained of the same general form as the on shown in Fig. 5.

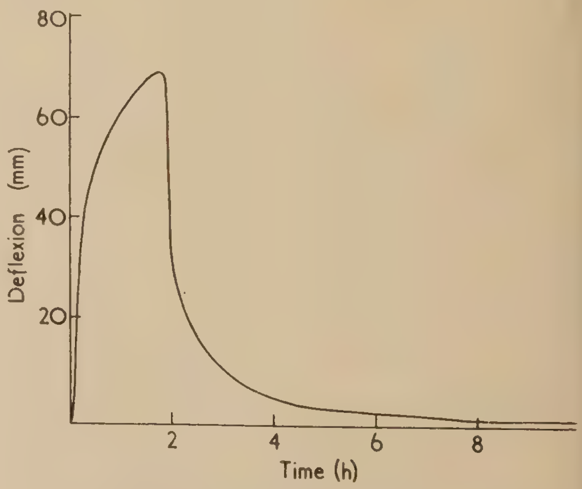


Fig. 5(*a*). Heat produced by the reaction of water vapour with calcium oxide

If we take, for example, the deflexion produced by the ease of 10^{-6} cal at a steady rate of 10^{-8} cal/s for 100 s

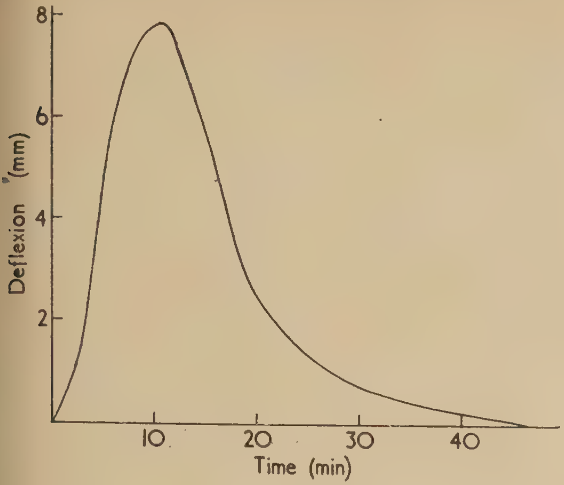


Fig. 5(*b*). Heat produced by the oxidation of carbon monoxide

e maximum temperature attained follows from the equation:
te of temperature rise

$$= \frac{\text{rate of input of heat}}{\text{heat capacity}} - \frac{\text{rate of loss of heat}}{\text{heat capacity}}$$

$$\frac{d\theta}{dt} = \frac{k}{c} - \frac{K\theta}{c}$$

here $k = 10^{-8}$ cal/s, $c = 1$ cal/°C, $K = 1 \cdot 56 \times 10^{-2}$ cal er s per °C, $\theta =$ temperature rise, from which $(\theta)_{t=100} =$ $\cdot 1 \times 10^{-7}$ °C or about one-half of the temperature of)$^{-6}$ °C produced by a perfect adiabatic calorimeter of the me heat capacity.

In a perfect isothermal calorimeter fitted with a Paschen ilvanometer as described above this would produce a eflexion of 1·1 mm. This is about four times the steady eflexion produced by a perfect adiabatic calorimeter such ; described by Whipp, largely because of the smaller number couples in Whipp's calorimeter which were necessary to duce the heat transfer.

However, the deflexion produced by the isothermal lorimeter is only transient and decays to 1/100 of its maxium value in about five minutes after heat ceases to be leased, but with photographic recording this graph of eflexion/time can be spread out over a convenient area and tegrated to give an accurate measure of the heat produced.

STABILITY

No difficulty was experienced in obtaining a steady reading om the apparatus and it appeared to be practically unfected by temperature fluctuations in the surrounding water ath. Recently the calorimeter has been used with a galvanometer of 12·6 Ω internal resistance and sensitivity 64·0 mm/μA in the photographic recorder employed, giving an overall sensitivity of 27 mm per cal per h. Fluctuations due to external temperature changes have been reduced to negligible proportions by careful insulation and thermostating the surroundings to ± 1° C.

CONCLUSION

The main advantages of this type of apparatus appear to be:

(1) a reasonable flow of gas can be passed through the calorimeter without sacrificing sensitivity;

(2) the apparatus will measure both a rate of heat production and the total quantity of heat produced;

(3) the sensitivity is independent of the specific heat of the reacting materials.

These advantages are due to the high heat transfer coefficient along the thermocouple wires and this also allows the maximum conversion of heat into electrical energy.

The apparatus has been used during the past year to measure heats of wetting and heats of oxidation of coal and it is hoped to publish the results of these experiments in the near future.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the help received from members of the Applied Mathematics Laboratory, Department of Scientific and Industrial Research, Wellington, who deduced equation (10) from a more general solution,(7) and he is also indebted to Professor J. Ivon Graham, Director of the Coal Research Section, Otago University School of Mines, whose interest and advice has stimulated the work.

During the period when most of the work described in this paper was carried out, the author was employed by the Dominion Laboratory, Wellington, and seconded to the Otago School of Mines, Dunedin. The paper is published by permission of the Director of the Dominion Laboratory, Wellington.

REFERENCES

(1) STOTT, J. B., and BAKER, O. J. *Fuel*, **32**, p. 415 (1953).

(2) THOMSON, SIR W. *Mathematical and Physical Papers*, **1**, p. 240 (1884).

(3) STAFFORD HATFIELD, H., and WILKINS, F. J. *J. Sci. Instrum.*, **27**, p. 1 (1950).

(4) WHIPP, B. *Phil. Mag.*, **18**, p. 745 (1934).

(5) SWIETOSLAWSKI, W. *Microcalorimetry* (New York: Reinhold Publishing Corp., 1946).

(6) GLAZEBROOK. *Dictionary of Applied Physics*, **2**, p. 366 (London: Macmillan and Co. Ltd., 1922).

(7) CARSLAW, H. S., and JAEGER, J. C. *Conduction of Heat in Solids*, p. 85 (Oxford: Clarendon Press, 1947.)

A cell for kinetic measurements of gas evolution from systems irradiated by fast electron beams

By C. B. Amphlett, B.Sc., Ph.D., and T. F. Williams, B.Sc., Atomic Energy Research Establishment, Harwell, Be

[*Paper received* 10 *October*, 1955]

By employing a mercury bellows manometer and balancing circuit it has been found possible to measure rapid rates of gas evolution from systems undergoing decomposition under fast electron bombardment from an electrostatic generator. The apparatus is reasonably robust, rapid in response, and gives reproducible results. Much slower rates of gas evolution can also be measured by the same technique.

In designing a cell for irradiating liquid systems with electron beams the major requirements are that the window thickness should be as little as possible, to minimize extraneous energy loss, and that the liquid depth should also be small, since the range of 1 MeV electrons is only about 0·5 cm in matter of unit density. Furthermore, since the target area must be heavily shielded, any measurements carried out during an irradiation must be made at some distance; in the present case this involved working in a room on a different floor and not immediately above the target room. It was already known that in the systems to be studied, namely, organic compounds dissolved in strong solutions of nitric acid, gas evolution can be extremely rapid, so that a rapidly-responding and robust system was required.

The cell shown in Fig. 1 was employed in experiments with a downward-firing beam of electrons (0·4–1·25 MeV) from a Van de Graaff generator. The irradiation cell *A* was constructed from 40 mm diameter Pyrex tubing and had a depth of 20 mm; the window *B* was a disk of uniformly thick Pyrex glass, 0·5 mm thick, protected by the guard ring *C*, which also served to prevent the bath liquid from covering the window. The cell was filled *via* the capillary tube *D*, which was then sealed off; the cell and contents were then evacuated and finally sealed off at *E*. Gases liberated during the reaction saturate the liquid and fill the gas bulb *F*, of 40 mm diameter and 50 mm long. By varying the ratio of volumes of liquid and gas space it is possible to calculate and apply corrections for the volume of gas dissolved in the liquid; in most of the experiments the liquid and gas volumes were 15 and 44 cm^3 respectively. At the end of a run the cell was sealed to a vacuum line at *G* and the gases removed for analysis by opening the break-seal. Fig. 2 shows a later design of cell used for experiments with a horizontal beam from the same generator; only the cell is shown, the gas bulb and manometer being identical with those in the first cell.

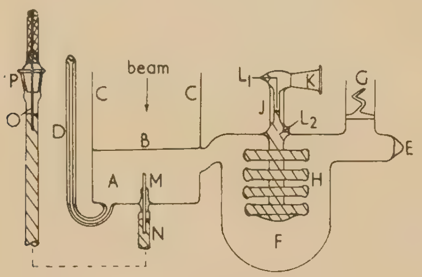


Fig. 1. Irradiation cell and gas bulb for use with vertical beam

The cylindrical reaction cell *A* was 10 mm deep and 35 in diameter, with a capacity of approximately 10 cm^3. guard-ring *C* was sealed to a standard ground joint *R*, wh fitted into a corresponding joint inside the front face of water-bath; this served both to fix the apparatus in posit

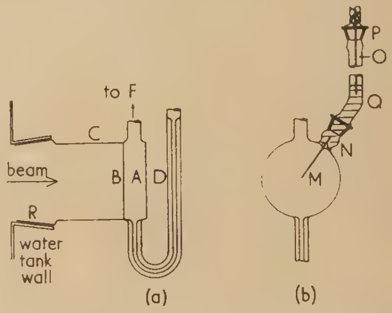


Fig. 2. Irradiation cell for use with horizontal beam (*a*) Side elevation. (*b*) Front elevation.

and to protect the window *B* from the bath liquid. T advantages of the second design of cell are that it perm easy escape of gases from the liquid and from the radiati field, and also permits the use of shallower cells without und difficulties of construction. Where the alternatives of verti or horizontal beam irradiation are available, the seco design is definitely superior, but the first may be used qu successfully in cases where the presence of a gas phase abo the liquid and exposed to the radiation is not a disadvanta

The pressure within the cell during irradiation w measured by means of the mercury bellows manometer which is a modification of that originally described Spence.(1) Changes of pressure cause elongations a contractions of the mercury-filled Pyrex bellows, which a followed by the movement of the mercury column in t capillary *J* (Fig. 1). In the original design this was re directly by means of a cathetometer, but the present syste employs a balancing air column and a null method. Bello were constructed from 8 mm Pyrex tubing, with four co volutions of 25 mm diameter; using 0·5 mm inner diame capillary tubing sensitivities up to 20–30 cm/atm we obtained. Before sealing into the gas bulb, all bellows we tested for sensitivity and for robustness under operati conditions. Bellows were finally filled with mercury, aft sealing into the unit, by the standard procedure for filli manometers.(2) Calibrations were usually reproducible ov several cycles of pressure increase and decrease, althou hysteresis was occasionally noted after sudden severe pressu changes; this, however, is of little importance in a null metho ere the movement in the capillary is small. As emphasized Spence, the temperature of the bellows must be maintained stant, since it acts as a sensitive thermometer. The perature coefficient of a typical bellows is equivalent to a ssure change of approximately 1 mm of mercury per ° C; in order to ensure accuracies of ±1 mm in pressure asurements the bellows temperature must therefore be intained constant to better than 0·1° C. The inside of capillary tube *J* was roughened with carborundum wder to minimize sticking.

After evacuation, the cell was mounted in a bath through ich water was circulated from a thermostat, the water-level ng such that the gas bulb was completely covered. The ancing side of the gauge, at atmospheric pressure, was nected at the waxed joint *K* to some 40 ft of 1 cm diameter ing leading to the balancing manometer on the upper or, together with facilities for evacuation and admission of . Air was slowly withdrawn from the balancing side until rising mercury column in *J* made contact between the gsten leads L_1 and L_2; these were sealed through the wider ing to avoid breaks in the mercury column which resulted eads were sealed through the capillary. Connexions from and L_2 were taken to a 6 V dry battery, 10^4 Ω resistance, d milliameter, alongside the balancing manometer; make d break between the contacts was readily indicated in this y. By employing a null method the length of the capillary y be as little as 10 mm, enabling the cell to be mounted se to the generator window.

Once the system had reached thermal equilibrium the ige was finally balanced and the balancing pressure noted; s is, of course, an arbitrary value depending on the precise ount of mercury used to fill the bellows, and was taken as zero pressure, thus correcting all subsequent values for initial vapour pressure of the system. Irradiation was n begun, and a measured excess pressure admitted to the ancing line; the time was noted when contact was again de, more air was admitted, and the procedure was repeated. this way a series of times was obtained corresponding to viously chosen values of pressure, the latter being varied cording to the prevailing rate of pressure increase. By ploying the precautions detailed above it was found ssible to follow rapid evolution of gases with a good degree reproducibility, the response being virtually instantaneous spite the presence of about one litre of dead-space in the ancing line, and the mercury column being remarkably e from sticking troubles. In the reactions studied, rates pressure increase ranged from less than 0·1 to 186 mm of rcury per min, and with two operators it was possible obtain as many as six readings per minute over the eply-rising portion of the curve; the need for this is parent when we see that in some instances a pressure e of 1000 cm of mercury was developed in approximately een minutes. For pressures above atmospheric, the closed b of the balancing manometer was filled at atmospheric ssure and all subsequent readings corrected for com- ssibility. Fig. 3 shows the record of a typical experiment,(3) ne of the readings being omitted for the sake of clarity; degree of reproducibility can be judged from the following irs of duplicate results under different conditions (all are ximum rates of gas evolution in millimetres of mercury per nute): 27·6, 27·3; 22·5, 22·3; 22·1, 22·5; 11·9, 11·6.

The energy input into the system was measured from the beam voltage (corrected for window losses) and the charge collected on the lead *M*; the latter was of platinum, welded to tungsten and sealed through the bottom of the cell into the mercury-filled tube *N*. Into the latter dipped the wire *O*, which was sealed through the joint *P* and soldered to the shielded lead to the current-measuring device, the shielding being earthed and the joint *P* securely waxed. The current was fed to earth *via* a high resistance and sub-standard microammeter, currents of less than 1 μA being amplified before measurement. All precautions were taken to ensure that there was no appreciable extraneous leakage to earth. In the second type of cell (Fig. 2), the design was made more compact by bringing the lead *M* through to a short tube *N*, fitted with a ground joint; a connecting tube *Q*, waxed into the joint at *N*, served to carry the connexion above the water-level to where the shielded lead was brought in *via* the joint *P*. When the cell was not being used for irradiation, the tube *Q* could be dismantled and the mercury removed from *N*.

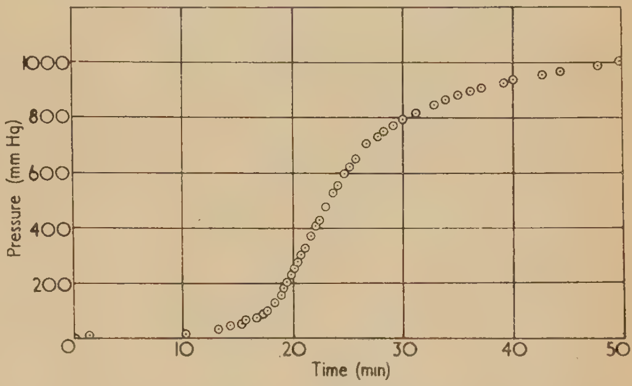


Fig. 3. Typical record for radiation-induced decomposition of nitric acid-organic system

As well as being used for the radiation-induced decomposition of nitric acid-organic systems, similar cells have also been used for thermal reactions in the absence of radiation where the induction periods are longer than the time required to attain thermal equilibrium on first mounting the cell in the bath.

ACKNOWLEDGEMENTS

We are indebted to Mr. S. W. Osborne for construction of the cells, and to Mr. J. D. Milne and Mr. B. Morris for operation of the electrostatic generator.

REFERENCES

(1) Spence, R. *Trans Faraday Soc.*, **36**, p. 417 (1940).

(2) Farkas, A., and Melville, H. W. *Experimental Methods in Gas Reactions*, p. 81 (London: Macmillan and Co. Ltd., 1939).

(3) Amphlett, C. B., and Williams, T. F. A.E.R.E. C/R–761 (1952).

Small angle X-ray diffraction unit

By C. R. Worthington, Ph.D.,* Physics Department, University of Adelaide, South Australia

[*Paper received* 24 *August*, 1955]

A small angle X-ray diffraction unit consisting of a rotating anode X-ray tube and an evacuated X-ray camera is described. The X-ray camera can resolve a spacing of 1000 Å with a separation of 2 lines per mm at the X-ray film. Photographs of the first twelve orders of moist collagen have been obtained, fully resolved, with exposures of less than one hour.

Low angle X-ray diffraction methods are of considerable importance in the study of proteins and, in particular, have been much used in the investigation of collagen fibres. Using commercial sealed-off X-ray tubes the exposure times needed to obtain satisfactory resolved diffraction patterns from collagen may be of the order of days and it is desirable to reduce this time as much as possible. After consideration of a number of possible solutions to this problem a unit was constructed consisting of a rotating anode X-ray tube and an evacuated slit aperture camera with photographic recording. The camera was required to resolve fibre spacings up to 1000 Å with a separation of 2 lines per mm at the X-ray film. Copper radiation was to be used so that a specimen-to-film distance of 12 in. was required with a total camera length of at least 24 in. The elimination of air scatter over this long path is essential to minimize the background on the X-ray film and thus allow the detection of very weak diffraction lines. Accordingly the camera was evacuated by a mechanical backing pump. The design of the slit system is an important matter and a detailed consideration of this problem(1) led to the dimensions given here. A rotating anode X-ray tube of moderate focal area was chosen as the best source of X-rays to use in conjunction with the small angle X-ray camera. This equipment has been in use for the last two years with very satisfactory performance.

THE X-RAY TUBE

The rotating anode X-ray tube was built according to Taylor's(2) design with such modifications as were dictated by the availability of materials and workshop facilities. The bearings for the anode were altered so that commercial ball races could be used. Gaco oil seals (by George Angus and Co.) packed with silicone or Apiezon vacuum grease fitted over a spacer shaft of stainless steel between the ball races. This spacer shaft was of correct length so that the inners of the ball races ran freely. An O-ring acted as the vacuum seal between the anode and the spacer shaft. The insulator for the filament assembly was made from a glazed porcelain cylinder 9 in. long, 3 in. outer diameter and $\frac{7}{16}$ in. wall thickness. Mild steel flanges were cemented to each end of the cylinder by means of the thermo-setting polymer Araldite (by Aero Research Ltd.) cured in an oven at 180° C for one hour. Mechanically sound joints were made in this way and to ensure vacuum tightness they were covered with Apiezon wax. The porcelain cylinder was then bolted to the body of the X-ray tube while an O-ring, let into the metal flange, acted as the vacuum seal. The filament head assembly fitted into the other metal flange which, again, had an O-ring to seal the joint. The filament head could then be withdrawn from the X-ray tube and replaced in exactly the same position. The filaments consisted of four turns of 0·011 in. tungsten wire in a length of 0·5 cm and were inserted with the aid of a jig. Consequently, when a filament burnt out, it co be replaced quickly and accurately. This arrangement g a focal area of 6 × 1 mm, the long dimension being horizon

The windows of the X-ray tube were positioned so that angle ϕ between the X-ray beam and the anode sur could be varied from 0 to 9°. According to Bolduan Bear(3) the optimum angle of ϕ for copper radiation is than 1°. The optimum angle at various voltages was measu experimentally with this unit by the present author.(1) results obtained indicated the use of moderate high volt about 30 kV, while the optimum angle ϕ was 2° for 30 When copper radiation was used the X-ray tube wind were of nickel foil 0·02 mm thick, which also acted a filter to eliminate the Kβ radiation. The anode was dri at 1000 rev/min by a rubber-mounted motor shown Fig. 1. Because of the precise alinement of the apertu and the X-ray source, it was essential that the X-ray t and camera should be of rigid construction and free fr vibration.

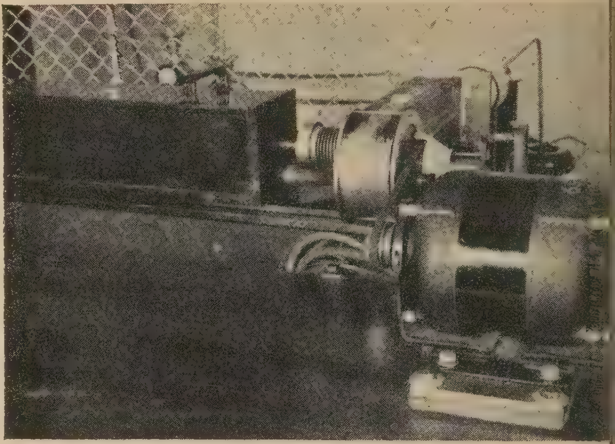


Fig. 1. Photograph of the small angle apparatus

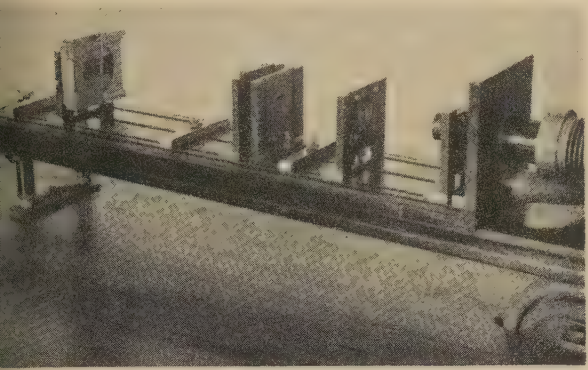
The high tension supply consisted of a 5 kVA d.c. out from a full wave rectifier circuit with a maximum out voltage of 60 kV. An 0·2 μF smoothing condenser used with a series choke of 40 H, 2000 Ω included in the h tension lead. Safety devices included relays operated cooling water pressure, X-ray tube current overload re and a relay which operated if the rate of rotation of anode dropped below 800 rev/min. The X-ray tube been operated at about 2·5 kW, usually at 30 kV 80 n with a focal area of 6 × 1 mm. The running time for Gaco seals was about 150 hours although better results h been obtained. Filament lifetimes were somewhat varia but an average lifetime was about 400 hours. Under norr operating conditions a vacuum of 10^{-5} mm of mercury quite usual.

---

* Now at Brooklyn Polytechnic Institute, U.S.A.

THE DIFFRACTION CAMERA

e camera consisted essentially of two collimating slits, ard aperture, a specimen holder and a film cassette with ntral beam stop. These components were mounted on ptical bench and were adjustable along the camera axis. otograph of the X-ray camera with the cover removed own in Fig. 2 in which the positions of the various ponents are the actual positions used in resolving the



g. 2. Photograph of the camera with the cover removed

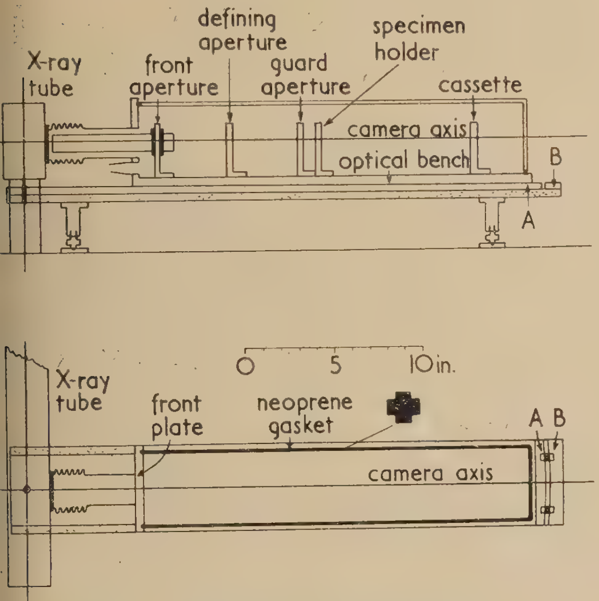


Fig. 3. Side and top view of camera

l angle pattern of collagen. A drawing of the side and views of the camera and its relation to the X-ray tube hown in Fig. 3.

e camera was enclosed by a cover of $\frac{1}{4}$ in. mild steel in orm of the top, sides and one end of a rectangular box hich the optical bench and the front plate attached to it tituted the remaining sides. A neoprene gasket, of cross-on shown in Fig. 3, was fitted into the grooves cut in optical bench and the front plate, and the cover seated his. Brass spacers were attached to the optical bench rovide additional support for the cover sides when the era was evacuated. A pumping line led from the front of the camera by way of a tap and reservoir to the backing pump. The reservoir was evacuated and, then, with the cover in position on its gasket, the tap was opened and the sudden reduction in pressure was sufficient to pull the cover hard on to the neoprene, thus making an effective vacuum seal. Without the reservoir it was difficult to obtain a vacuum-tight seal at the gasket.

The camera axis shown in Fig. 3 was horizontal and passed through the centre of the focal area on the anode. To allow adjustment of the angle ϕ between the camera axis and the anode surface the camera was connected to the X-ray tube by a flexible copper bellows, and the optical bench was mounted on a steel plate *A* pivoted about a point vertically below the centre of the focal area on the anode. The optical bench could be moved in a horizontal plane about a pivot fixed to the mild steel supporting plate. The pivot was adjustable in a direction perpendicular to the camera axis. At the far end of plate *A* the plate *B* was attached. This was provided with a scale graduated in degrees from which the angle ϕ could be read. The camera axis was levelled by three screws which supported the camera on the table.

The three apertures, front aperture, defining aperture and guard aperture were mounted on inserts which fitted into insert holders attached to the optical bench. The insert holder is shown in Fig. 4. All inserts *s* and insert holders were interchangeable. The insert holder was made of $\frac{1}{4}$ in. mild steel and was clamped to the optical bench by means of a 1 B.A. screw. Insert *s* fitted securely into the insert holder and the vertical adjustment was provided by the 2 B.A. screw. This was the only vertical adjustment required for the alinement of the different apertures. The defining aperture is shown in Fig. 5. Only the defining aperture need be described as the other apertures are similar. The movements required were vertical, horizontal and rotary. The apertures were mounted on a circular piece of mild steel *P* which could be rotated and then clamped to insert *s*. This allowed the apertures to be accurately alined with the vertical. The horizontal movement was the most critical and was provided by a 10 B.A. screw under spring tension to eliminate backlash. The front aperture and its horizontal movement was attached to the end of a hollow tube which was firmly clamped to insert *s*. This allowed the front aperture to be very close to the X-ray tube window. The guard aperture required a finer horizontal movement and the 10 B.A. screw was associated with a worm wheel drive which allowed the

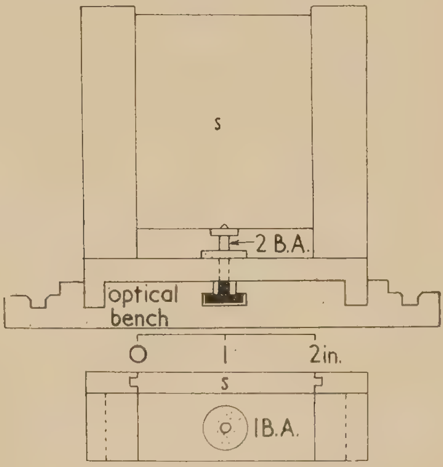


Fig. 4. Insert holder

aperture to move a distance of 0·00025 in. for each revolution on the 10 B.A. screw. The apertures consisted of two pieces of correctly surfaced lead which were glued on to a mild steel base insert *Q*. They were prepared by the method given by Bolduan and Bear.(3) These lead apertures gave much less scatter from the defining aperture than carefully machined tantalum and tungsten slits, which were also tried.

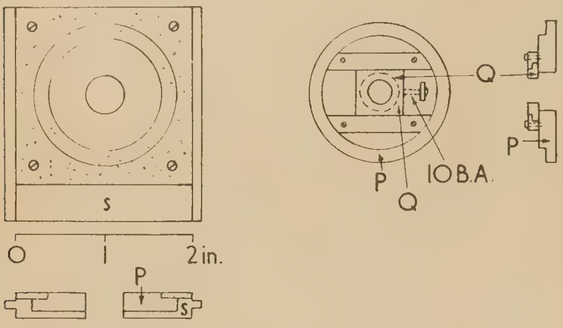


Fig. 5. Defining aperture

The specimen holder is shown in Fig. 6. An additional movement was required to allow the specimen to be tilted with respect to the X-ray beam. The specimen holder shown is for dry fibres which were exposed to the vacuum of the X-ray camera. To mount the specimen, the insert *s* was removed so that the specimen could be alined very carefully. The specimen holder for wet fibres could be put into insert *s* in place of *P*. This cell had two beryllium windows 0·008 in. thick for X-ray transmission while an O-ring formed the vacuum seal. The cassette and cassette holder are shown in Fig. 2. The cassette fitted securely into the holder and was easily removed. A number of X-ray films could be used in the cassette and, in most cases, a film pack of three X-ray films interleaved with black paper was used. The beam stop was a piece of lead 0·026 in. wide and 1 in. long which was firmly attached to a brass wire. The horizontal movement was provided by a 10 B.A. screw under spring tension. When the cassette was removed, the insert *s* and the cassette holder had a ½ in. diameter opening directly behind the beam stop. This allowed the beam stop to be alined using a photoelectric multiplier X-ray detector as described below.

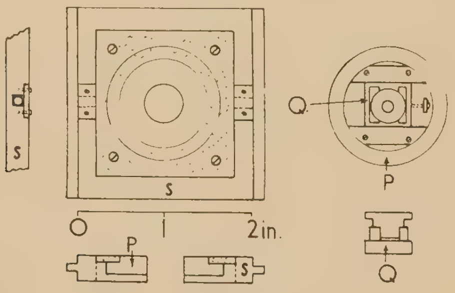


Fig. 6. Specimen holder

SLIT DIMENSIONS

The slit system which satisfies the requirements of small angle diffraction(1) has the front aperture larger than the defining aperture and should be such that the centre of the film subtends the same angle at both the front and defi apertures. The slit dimensions which have been use resolve the collagen pattern using copper radiation ar follows:

front aperture 0·0034 in., defining aperture 0·0022
guard aperture 0·0057 in.;
front aperture to defining aperture 9·9 in.;
defining aperture to guard aperture 4·2 in.;
guard aperture to specimen 0·4 in., specimen to film 9
width of X-ray beam at the X-ray film 0·011 in.;
width of X-ray scatter allowed by the guard aper
0·022 in.;
width of the beam stop 0·026 in.

CAMERA TECHNIQUE

The alinement of the camera was performed using an X detector consisting of a fluorescent screen and a photoele multiplier (R.C.A. type 931A) housed in a light-tight case a black paper window to admit the X-ray beam. This could be mounted on the optical bench as required. multiplier was battery operated and was connected t stabilized vacuum tube voltmeter. It was linear in resp and sufficiently sensitive that the alinement procedure c be carried out with only 5 mA X-ray tube current. alinement was carried out as follows:

(1) the front aperture was alined on the camera axis, u a slit in front of the X-ray detector to define the camera a

(2) with the X-ray detector behind the defining aper the latter was adjusted with respect to the front ap until the X-ray detector gave a maximum response;

(3) the beam stop was set approximately as judged b minimum response of the detector. The final adjustment made photographically with no specimen and no gu aperture in position. It was not necessary to evacuate camera and, with only a few milliampere hours exposure scatter on either side of the beam stop was apparent;

(4) the guard aperture was next alined by placing the X detector behind it and adjusting for maximum respo This adjustment is the most critical, and was checked taking a photograph of long milliampere hours expo without a specimen, and with the camera evacuated, to en that the scatter observed in the absence of a guard aper had been eliminated. The camera was then ready for us

During the course of a prolonged exposure the aliner was checked from time to time, usually at intervals of hours. This was necessary because the anode assembly apt to move slightly on its neoprene gasket, thus moving

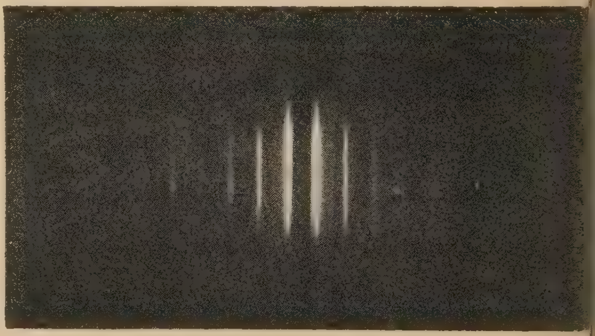


Fig. 7. Photograph of wet collagen small-ang diffraction

al area relative to the camera axis. The error could be
rected by adjustment of the movable pivot for maximum
ponse of the X-ray detector placed behind the guard
rture. This operation took only five minutes.

PERFORMANCE

The apparatus has been extensively used in the study of
lagen fibres. A brief report⁽⁴⁾ on some of this work has
eady appeared. A typical pattern from wet collagen, in
s case from kangaroo tail tendon, is shown in Fig. 7 which
ws the first twelve orders of diffraction. The spacing was
Å. This picture was obtained with the camera dimensions
oted above, and using nickel filtered copper radiation with
X-ray tube operated at 30 kV, 80 mA; the exposure time
s 45 min. The peak intensity in the first order of density
= 1·0 above background was obtained within twenty
nutes exposure under these conditions. To obtain photo-
phs suitable for microphotometry of the first twenty-five
lers or so, a film pack, consisting of three films separated
black paper, was used together with a separate very short
posure to record the first few orders at a suitable density
measurement. In this way, careful measurements of the
ensities of twenty-five orders of wet and twenty-three of dry collagen have been made. It may be added that these measurements have been confirmed using chromium radiation, but this offers no great advantage over copper radiation in the study of collagen.

ACKNOWLEDGEMENTS

It is a pleasure to thank Dr. S. G. Tomlin for his help and encouragement during the course of this work. I wish to thank Mr. L. Hettner and Mr. J. Gascoigne of the Physics Workshop who completed the construction of the X-ray tube and camera respectively.

This work was supported by a University Grant, 1951–2, and a Commonwealth Scientific and Industrial Research Organization Australian Studentship, 1953–4.

REFERENCES

(1) Worthington, C. R. Ph.D. Thesis, University of Adelaide (1955).
(2) Taylor, A. *J. Sci. Instrum.*, **26**, p. 225 (1949).
(3) Bolduan, O. E. A., and Bear, R. S. *J. Appl. Phys.*, **20**, p. 983 (1949).
(4) Worthington, C. R., and Tomlin, S. G. *Nature* [*London*], **175**, p. 811 (1955).

A wide range, recording, logarithmic photometer circuit

y P. Hariharan, M.Sc., A.Inst.P., and M. S. Bhalla, M.Sc., National Physical Laboratory of India, New Delhi, India

[*Paper received* 22 *August*, 1955]

The circuit described uses a photomultiplier tube operated as a range compressor, followed by a logarithmic amplifier, to obtain an accurately logarithmic response over an illumination range greater than $10^6 : 1$. It can be utilized, in conjunction with a recording milliammeter or an oscillograph, for brightness *versus* time measurements wherever extreme brightness ranges are encountered.

any photometric problems involve continuous measure-
ents over a large brightness range. In such cases, the use
a photoelectric circuit with a logarithmic response over a
de range eliminates the necessity of range switching and
sures uniform accuracy over the whole scale.

Earlier attempts in this direction have mainly utilized the
arded field characteristics of triodes.⁽¹, ², ³⁾ While such
cuits can theoretically yield a logarithmic response over a
ige exceeding $10^4 : 1$, insulation requirements set a lower
it to the grid current which can be measured accurately.
rther, because of unfavourable polarity relationships, it is
ficult to use a photomultiplier tube instead of an ordinary
otocell to obtain increased sensitivity.⁽⁴⁾

More recently, a circuit has been described⁽⁵⁾ which uses
principle of dynode voltage feedback, applied to a photo-
iltiplier tube, to obtain a roughly logarithmic response;
s is corrected to give a closely logarithmic characteristic by
mpensating shunts.⁽⁶⁾ Circuits based on this principle
ve the advantages that fatigue of the photomultiplier tube
practically eliminated, and high sensitivity can be obtained
thout any risk of accidentally damaging the photocell by
erloads. Such circuits can cover a range exceeding six
cades,⁽⁷⁾ but the accuracy which can be obtained over any
en range is limited by the number of corrective shunts
ed. With two corrective shunts, reasonable accuracy can
obtained only over an illumination range of $10^3 : 1$, and
more than two are employed, their adjustment becomes a
her tedious process.

The circuit described in the present paper applies the principle of range compression, developed by the authors in connexion with a linear densitometer,⁽⁸⁾ to yield an accurately logarithmic response over an extremely wide range without the use of any correction circuits.

THEORY OF THE CIRCUIT

The light sensitive element used in this circuit is a type 931A photomultiplier tube operated at constant anode current. A negative feedback amplifier is used to control the dynode voltage per stage, and hence the gain of the photomultiplier, so that the anode current does not change when the light flux incident on the photocathode varies. It can then be shown⁽⁸⁾ that the relation between the light flux F and the dynode voltage V is of the form:

$$F \propto (V/V_1)^{-N\beta} \qquad (1)$$

where V_1 and β are tube constants, and N is the number of dynode stages.

If, now, the dynode voltage is applied to an amplifier with a logarithmic response, the output voltage v can be defined by the relation:

$$v = \log V + C \qquad (2)$$

where C is a constant. Combining this with equation (1), we have:

$$v = -(1/N\beta) \log F + K \qquad (3)$$

where K is another constant. The output voltage is, therefore, proportional to the logarithm of the incident light flux.

For most commercial photomultiplier tubes of this type,(9) $N\beta$ is of the order of 6·6. If the range which the logarithmic amplifier will handle is the limiting factor, it follows then, from equation (3), that a logarithmic response can be obtained over 6·6 times this range, on a logarithmic scale. This was the case in the densitometer circuit described earlier,(8) which covered a density range of 2·5.

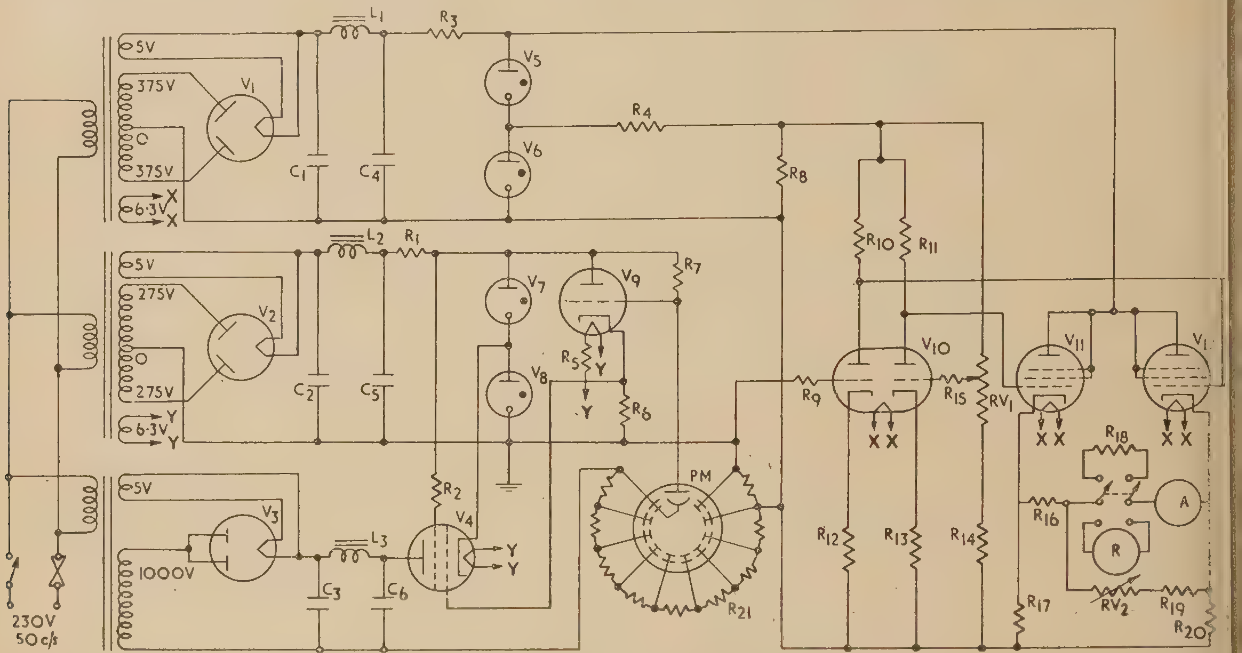


Fig. 1. Diagram of the logarithmic photometer circuit. Wirewound resistors are used throughout, with the exception of R_6, R_7, R_9, R_{10}, R_{11} and R_{15}

$R_1 = 5$ kΩ
$R_2 = 1$ kΩ
$R_3 = 4$ kΩ
$R_4 = 7·5$ kΩ
$R_5 = 5$ Ω
$R_6 = 330$ kΩ
$R_7 = 150$ MΩ
$R_8 = 2·5$ kΩ
$R_9 = 5$ MΩ
$R_{10}, R_{11} = 100$ kΩ
$R_{12}, R_{13} = 10$ kΩ

$R_{14} = 5$ kΩ
$R_{15} = 5$ MΩ
$R_{16} = 600$ Ω
$R_{17} = 1·5$ kΩ
$R_{18} = 1250$ Ω
$R_{19} = 2$ kΩ
$R_{20} = 1·5$ kΩ
$R_{21} = 7·5$ kΩ each

$RV_1 = 5$ kΩ
$RV_2 = 10$ kΩ

$C_1, C_2 = 8$ μF
$C_3 = 4$ μF
$C_4, C_5 = 32$ μF
$C_6 = 4$ μF

$V_1, V_2 =$ 5Y3GT
$V_3 =$ 5R4GY
$V_4 =$ 807
$V_5 =$ VR150
$V_6 =$ VR105
$V_7, V_8 =$ VR75

$V_9 =$ 6SF5
$V_{10} =$ 6SN7 GT
$V_{11}, V_{12} =$ 6AC7

PM = 931A

L_1–$L_3 = 8$ H

R = Esterline–Angus recorder

$A = 0$–1 mA meter

In the present circuit, the retarded field characteristics of a triode have been used to provide an output proportional to the logarithm of the dynode voltage. Since the range which such a logarithmic amplifier will handle is greater than 20 : 1, the illumination range over which a logarithmic response can be obtained is now limited only by the range over which the photomultiplier characteristics obey equation (1).

CIRCUIT DETAILS

Fig. 1 is a diagram of the photometer circuit. The high voltage power supply for the photomultiplier tube is a conventional half-wave rectifier circuit with a capacitor-input filter. The individual dynodes are supplied from a chain of equal bleeder resistors, the current through which is controlled by a negative feedback circuit. To ensure reliable operation over long periods,(10) the voltage developed across the anode resistor R_7 of the photomultiplier tube is applied to the grid of V_4 through V_9.

A separate power supply, stabilized by two voltage regulator tubes, provides the plate voltages for the photomultiplier tube PM and V_9, as well as the screen and cathode vol for V_4.

The voltage developed across the last resistor in the dy bleeder chain (between dynode No. 8 and dynode No. applied to one grid of a double triode V_{10} through R_9. grid of the other section of V_{10} is connected, through to the variable tapping on a potentiometer RV_1 in the bl supplying the plates. The plate currents of both sectio this tube are proportional to the logarithms of the currents which, over a fairly wide range, are proportiona the voltages applied to the grid resistors. The actual cha teristics obtained with a typical type 6SN7 tube are sh in Fig. 2. A simple preliminary calibration is advisable eliminate tubes with excessively high grid currents.(3)

The plates of V_{10} are directly coupled to the grids of and V_{12}, which act as a difference amplifier. The ou current is read either on a 0–1 mA meter A connected betw the cathodes of V_{11} and V_{12}, or from the chart of the Ester Angus recorder R, which can be switched into the circui series with it. Alternatively, the input terminals of a direc coupled oscilloscope, such as the Du Mont 304-A, can connected to the cathodes of V_{11} and V_{12}.

The symmetrical design of this section of the circuit h to minimize the effects of filament voltage fluctuation which, otherwise, the logarithmic amplifier would be q sensitive. Because of polarity requirements, the plate volta for these tubes are taken from a third, floating power sup also stabilized with two gas discharge tubes. Since resistances in the dynode bleeder circuit are comparati low, insulation requirements are not critical.

The meter zero is set by varying the potential applied to grid of the second half of V_{10} by means of the potentio- ter RV_1. The meter sensitivity can be adjusted by means the variable shunt resistance RV_2.

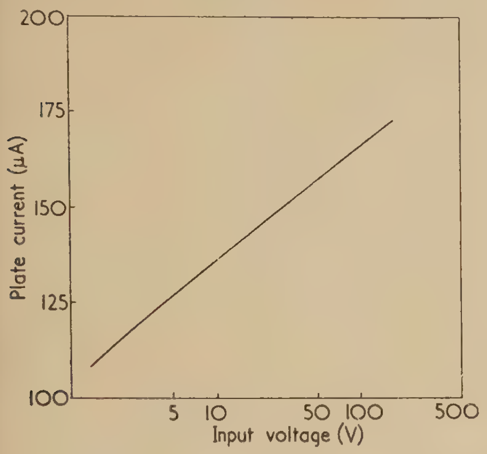


Fig. 2. Characteristic curve of the logarithmic amplifier circuit obtained with a typical type 6SN7 tube, showing the variation of the plate current with the input voltage applied to the grid resistor

CALIBRATION

The circuit was calibrated with a photometric bench and set of evaporated neutral filters.(11) To ensure maximum curacy, the meter current was read by measuring the voltage op across the series resistor R_{18} with a potentiometer. To luce the experimental difficulties, the calibration was per- rmed in two overlapping ranges, using an extra neutral er with a density of 3·0 to shift from one range to the other. The calibration was carried out by an incremental method.(6) serting a given neutral filter in the beam illuminating the otometer head produces a constant percentage change in light flux incident on it. If, therefore, the response of circuit were ideally logarithmic, the change in the output corresponding to this change in the incident flux, at different flux levels (obtained by varying the distance between the lamp and the probe unit containing the multiplier) would be the same. The deviation from this condition is a measure of the change in the slope of the response characteristic. Cumulative errors were avoided by repeating readings with filters having high as well as low densities.

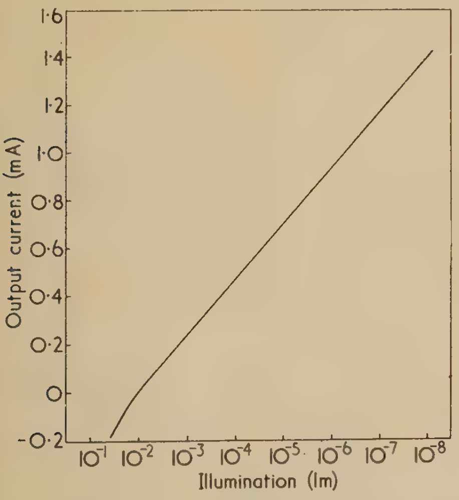


Fig. 3. Calibration curve of the logarithmic photo- neter obtained with a typical type 931A photomultiplier ube. The output current in the meter circuit is shown s a function of the illumination on the photomultiplier cathode

The response characteristic obtained with a typical type 931A photomultiplier tube is shown in Fig. 3. The characteristic is closely logarithmic for dynode voltages ranging from 17 to 120 V per stage. At lower voltages there is an abrupt change in the slope of the response curve. Measurements can be made over an illumination range of $10^6 : 1$ with an accuracy of ±0·03 on the logarithmic scale (6 — 0).

In actual operation, the circuit was found quite stable and free from drifts after a warm-up period of a few minutes. In spite of the extremely wide illumination range covered, multiplier fatigue effects were negligible. Replacement of the tubes is not critical, though the two halves of V_{10} as well as V_{11} and V_{12} should be reasonably matched for best results. The value of the cathode resistors of V_{10} has been chosen to give the best logarithmic characteristics for an average tube, and a very delicate control of any residual curvature of the characteristic is possible by varying them.

FREQUENCY RESPONSE

With an Esterline–Angus recorder (or any similar recording milliammeter) the response is limited by the recorder itself. When used in conjunction with an oscillograph, the frequency response of the circuit is limited primarily by the time constant of the photomultiplier anode circuit, due to R_7 and the associated tube and circuit capacitances. A level frequency response, up to approximately 250 c/s, can be obtained if these are minimized by mounting V_9 in the multiplier probe itself.

CONCLUSIONS

The photometer circuit described combines high sensitivity with stability and has an accurately logarithmic response over an illumination range exceeding $10^6 : 1$. While primarily designed for studying the luminous decay characteristics of phosphors and gaseous afterglows, other applications of the circuit can be easily envisaged.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. W. M. Vaidya for his interest in this work, and Dr. K. S. Krishnan, Director, National Physical Laboratory of India, for permission to publish this paper.

REFERENCES

(1) Hardy, A. C. *J. Opt. Soc. Amer.*, **18**, p. 96 (1929).
(2) Russell, J. *Rev. Sci. Instrum.*, **8**, p. 495 (1937).
(3) Attree, V. H. *J. Sci. Instrum.*, **32**, p. 41 (1955).
(4) Sweet, M. H. *Electronics*, **18** (3), p. 102 (1945).
(5) Sweet, M. H. *J. Opt. Soc. Amer.*, **37**, p. 432 (1947).
(6) Sweet, M. H. *Electronics*, **19** (11), p. 105 (1946).
(7) Plymale, W. S. *Electronics*, **26** (3), p. 143 (1953).
(8) Hariharan, P., and Bhalla, M. S. *Rev. Sci. Instrum.* To be published.
(9) Rodda, S. *Photo-electric Multipliers* (London: Macdonald and Co. Ltd., 1953).
(10) Sweet, M. H. *J. Soc. Motion Picture Engrs*, **54**, p. 35 (1950).
(11) Banning, M. *J. Opt. Soc. Amer.*, **37**, p. 686 (1947).

A fast multiple coincidence circuit

By B. Collinge, B.Sc., Ph.D., A. W. Merrison, B.Sc., and D. Eccleshall, B.Sc., Nuclear Physics Research
Laboratory, University of Liverpool

[*Paper received* 16 *August*, 1955]

A multiple coincidence circuit is described which provides for amplitude discrimination of fast photomultiplier pulses. A resolving time of 20 mμs is obtainable.

Counter telescopes are particularly useful in the measurement of angular distributions and in experiments where a comparatively small number of wanted particles is to be counted in a large background of unwanted radiations. The resolving time of the coincidence circuit, which follows the counters, determines the number of spurious counts recorded due to the random coincidence of counts in the individual detectors. The pulsed nature of the beams, from high-energy accelerators, increases the number of these spurious counts and makes it necessary to use coincidence circuits with a resolving time of the order of 10 mμs.(1) Many two-channel fast coincidence circuits have been described(2–8) and one of them(8) includes a scheme for amplitude discrimination. Two multiple coincidence circuits(1,9) are available but in these circuits no provision is made for amplitude discrimination.

The multiple coincidence circuit described here includes an amplitude discriminator. A trigger circuit generates pulses which are large enough to enable a simple diode coincidence circuit to be used. The resolving time is 20 mμs. The discriminator circuit in each channel will accept two pulses separated by 0·25 μs without loss of sensitivity. The dead time of a single channel, measured using large pulses is less than 0·1 μs. Each channel has been tested at counting rates of 10^5 per s.

THE CIRCUIT

A schematic diagram of a four-channel coincidence unit is shown in Fig. 1. The amplifier and trigger circuit comprising one channel is shown in Fig. 2.

The photomultiplier pulses are fed to the pulse-forming circuit containing V_{1b}(7,10) by means of the cathode follower V_{1a}. The pulses from the anode of V_{1b} are 20 mμs wide and are amplified by the secondary emission valve V_2. This arrangement was intended for use with photomultipliers type 931A (by the Radio Corporation of America) when some voltage gain is required. The circuit may be used with high gain photomultipliers although the gain provided in the circuit is then unnecessarily high. A suitable alternative amplifier has been described.(11)

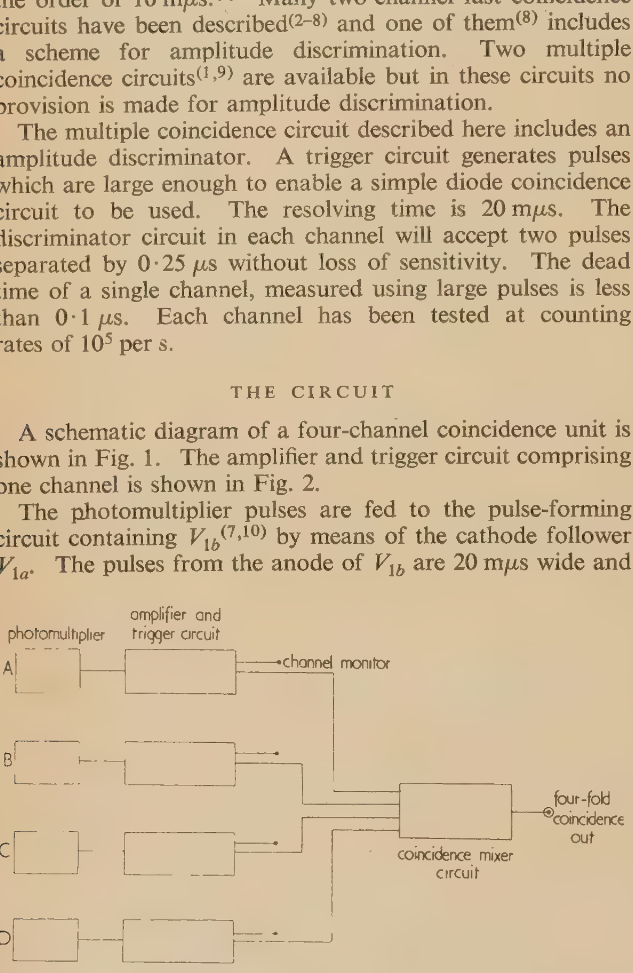

photomultiplier
amplifier and trigger circuit
A
B
C
D
channel monitor
four-fold coincidence out
coincidence mixer circuit

Fig. 1. Schematic diagram of a four-fold coincidence unit

The amplified pulses are fed into the diode discrimin which consists of diodes D_1 and D_2 and valves V_{3a} and The discriminator level is determined by the setting of

The trigger circuit shown is a modification of the circuit described by Moody, Maclusky and Deighto In the normal state V_4 is not conducting. When an ou pulse from the discriminator causes V_4 to conduct, the is driven positive and the anode current rises to a valu about 0·5 A. The time for which V_4 conducts is determ by the length L_2 of the coaxial cable connected between an and control grid. Negative pulses are fed to the co grid, *via* the diode D_3, causing V_4 to be regeneratively t off. The advantages of this trigger circuit are tha duration of the output pulse is constant and the va turned on for the minimum time. This ensures that recovery time of the circuit, and hence the triggering ra an optimum. The pulse fed to the coincidence mixer thr the coaxial cable L_1 is 35 V high. The duration of the p is 20 mμs (L_2 = 2 m) and the rise time is less than 10 r A coincidence between the output pulses from each ch is detected by the circuit shown in Fig. 3. When a coincid occurs, the four diodes D_1, D_2, D_3 and D_4 are cut off and potential at the cathode of D_5 changes by about 35 V. bias applied to the diode D_5 is set by means of the poten meter RV_1. Triple events are rejected when the bias is gre than 7 V and quadruple events are rejected when the bia greater than 35 V. The normal value of the bias is The pulses occurring at the cathode of D_5 are then ampl and fed to the flip-flop circuit, which comprises valves and V_4 which provides pulses for an external scaler.

The circuit can be modified simply to function so th pulse in one channel rejects a coincidence in the remai channels. Details of this modification are shown in Fig in which there are three coincidence channels and an a coincidence or "veto" channel. A pulse transformer is to invert the pulse from the anti-coincidence channel an is arranged that the diode D_4 is not conducting. It is neces to delay the coincidence pulses by 10 mμs, and lengthen veto pulse by about 20 mμs.

PERFORMANCE

The overall performance of the pulse shaping circ amplifier and discriminator, comprising one channel shown in Fig. 5. The voltage amplification is seven and circuit is linear to within 5% for input pulses of 1· amplitude.

The excellent performance of the circuits describe illustrated in Fig. 6. A three-channel coincidence arra ment was used to count a beam of positive π-mesons. curve was obtained by introducing time delays in one cha and recording double and triple coincidence rates. The r of triple to double coincidence rates is shown plotted a

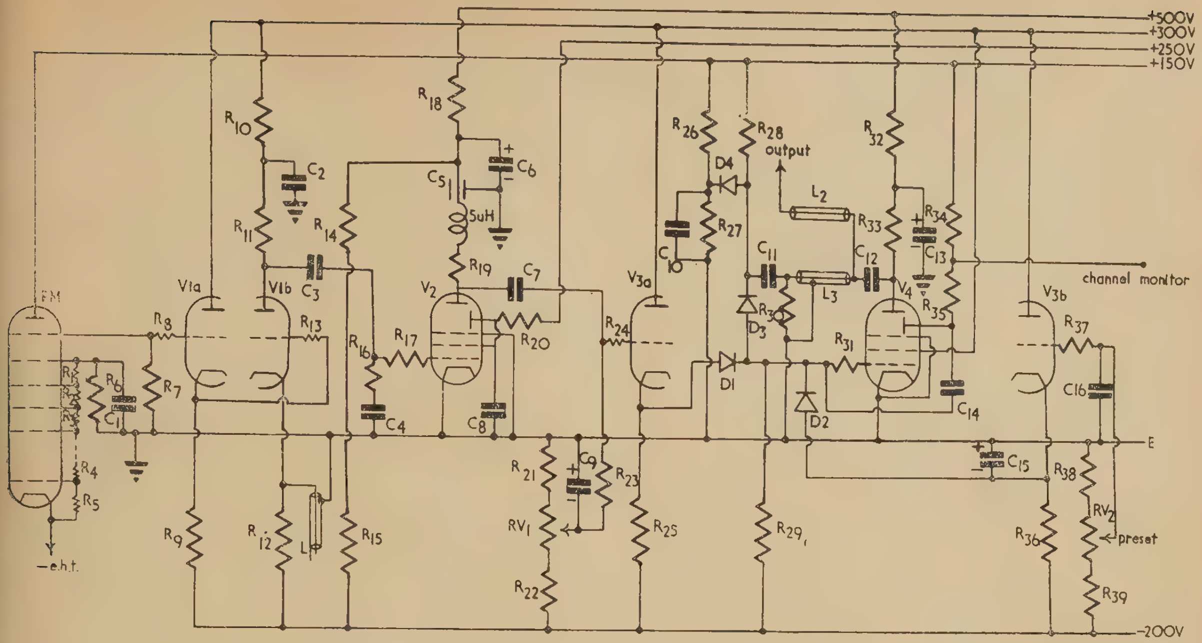

+500V
+300V
+250V
+150V
PM
V_{1a}
V_{1b}
R_{10}
C_2
R_{11}
C_3
R_{14}
R_{18}
C_5
C_6
5uH
R_{19}
C_7
V_2
R_{20}
R_8
R_{13}
R_{16}
R_{17}
R_1
R_2
R_3
R_6
C_1
R_7
C_4
C_8
R_4
R_5
–e.h.t.
R_9
R_{12}
L_1
R_{15}
R_{21}
C_9
R_{23}
RV_1
R_{22}
V_{3a}
R_{24}
R_{25}
R_{26}
R_{28}
output
D_4
C_{10}
R_{27}
L_2
C_{11}
R_{30}
D_3
D_1
D_2
L_3
R_{29}
R_{32}
R_{33}
C_{12}
R_{34}
C_{13}
R_{35}
V_4
R_{31}
C_{14}
channel monitor
V_{3b}
R_{37}
C_{16}
E
C_{15}
R_{38}
RV_2
preset
R_{36}
R_{39}
–200V

Fig. 2. Amplifier, discriminator and trigger circuit

R_1–R_6 = 1 MΩ
R_7 = 22 kΩ
R_8 = 22 Ω
R_9 = 41 kΩ
R_{10} = 6·8 kΩ
R_{11} = 270 Ω
R_{12} = 41 kΩ
R_{13} = 22 Ω
R_{14} = 1 MΩ (high stability carbon)
R_{15} = 560 kΩ (high stability carbon)
R_{16} = 10 kΩ
R_{17} = 22 Ω
R_{18} = 10 kΩ w.w.
R_{19}, R_{20} = 1 kΩ
R_{21} = 1 kΩ
R_{22} = 68 kΩ
R_{23} = 10 kΩ

R_{24} = 22 Ω
R_{25} = 41 kΩ
R_{26} = 150 kΩ
R_{27} = 1·8 kΩ
R_{28} = 330 kΩ
R_{29} = 100 kΩ
R_{30} = 120 Ω
R_{31} = 22 Ω
R_{32} = 12 Ω
R_{33} = 1·8 kΩ
R_{34} = 120 Ω
R_{35} = 1 kΩ
R_{36} = 47 kΩ
R_{37} = 1 kΩ
R_{38} = 1·8 kΩ
R_{39} = 56 kΩ

RV_1 = 10 kΩ
RV_2 = 2·5 kΩ

C_1 = 0·001 µF
C_2 = 0·1 µF
C_3 = 1000 pF
C_4 = 5 µF
C_5 = 200 pF
C_6 = 8 µF
C_7 = 100 pF
C_8 = 0·5 µF
C_9 = 5 µF
C_{10} = 0·25 µF
C_{11} = 0·01 µF
C_{12} = 1000 pF
C_{13} = 8 µF

C_{14} = 50 pF
C_{15} = 5 µF
C_{16} = 5 µF
C_{16} = 0·02 µF

$V_{1a, b}$ = CV455
V_2 = CVX2276
$V_{3a, b}$ = CV455
V_4 = EFP60

PM = photomultiplier

L_1 = 120 Ω line, open end
L_2, L_3 = 120 Ω line

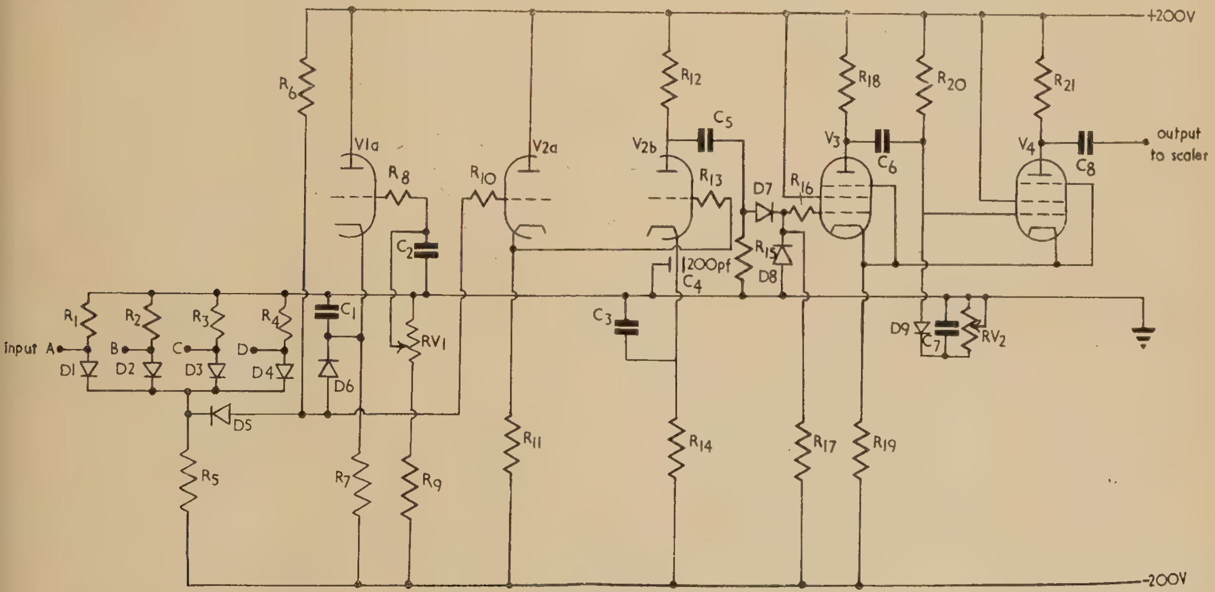

+200V
R_6
V_{1a}
R_8
R_{10}
V_{2a}
V_{2b}
R_{12}
C_5
R_{13}
R_{18}
R_{20}
R_{21}
V_3
C_6
V_4
output to scaler
C_8
D7
R_{16}
R_{15}
D8
C_2
1200pf
C_4
C_3
R_1
R_2
R_3
R_4
C_1
RV1
input A
B
C
D
D1
D2
D3
D4
D6
D5
D9
C_7
RV_2
R_5
R_7
R_9
R_{11}
R_{14}
R_{17}
R_{19}
–200V

Fig. 3. Four-fold coincidence mixer

R_1–R_4 = 120 Ω
R_5 = 10 kΩ
R_6 = 680 kΩ
R_7 = 47 kΩ
R_8 = 1 kΩ
R_9 = 100 kΩ
R_{10} = 22 Ω
R_{11} = 20 kΩ

R_{12} = 820 Ω
R_{13} = 22 Ω
R_{14} = 20 kΩ
R_{15} = 10 kΩ
R_{16} = 22 Ω
R_{17} = 1 MΩ
R_{18} = 3·9 kΩ
R_{19} = 10 kΩ

R_{20} = 100 kΩ
R_{21} = 1·8 kΩ

RV_1, RV_2 = 25 kΩ

C_1, C_2 = 0·01 µF
C_3 = 0·1 µF
C_4 = 200 pF

C_5 = 100 pF
C_6 = 50 pF
C_7 = 0·1 µF
C_8 = 0·01 µF

V_{1a} = CV455
V_{2a}, V_{2b} = CV455
V_3, V_4 = CV2127

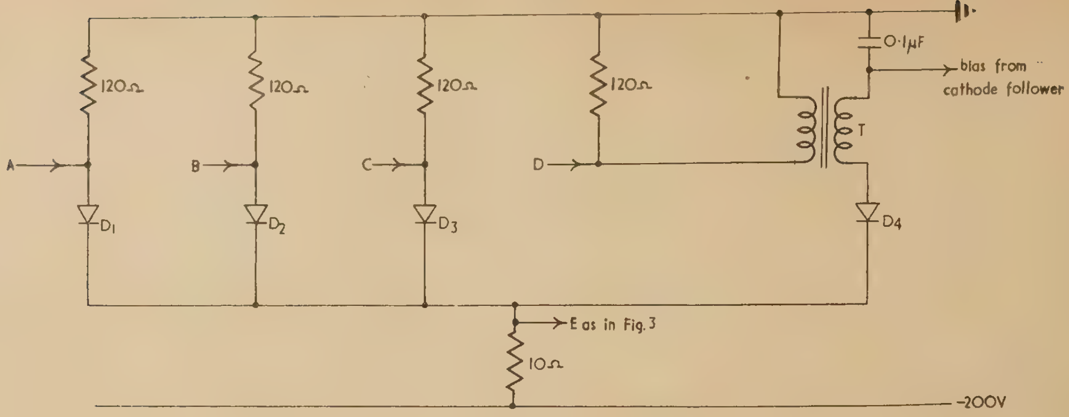


Fig. 4. Anti-coincidence arrangement

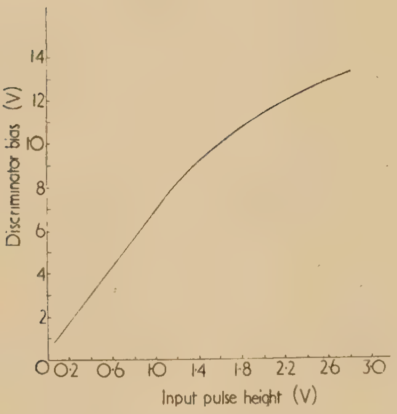


Fig. 5. Performance of pulse-forming circuit, amplifier and discriminator

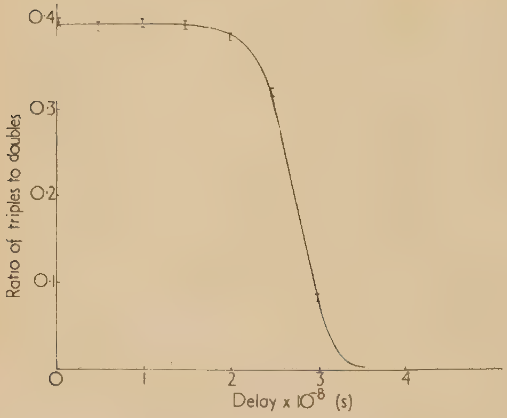


Fig. 6. Delay curve taken with 90 MeV mesons

function of time delay. The steep sides of the curve s that for a practical pulse height distribution the rise tim the amplifier and trigger circuit are adequate for resol times greater than 20 mμs. The flat top shows that efficiency of the electronics is 100%. The observed efficie of 40% is a result of the counter geometry.

ACKNOWLEDGEMENTS

One of us (D. E.) is indebted to the Department of Scien and Industrial Research for the grant which made this w possible.

REFERENCES

(1) Garwin, R. L. *Rev. Sci. Instrum.*, **24**, p. 618 (1953

(2) Bay, Z., and Papp, G. *Rev. Sci. Instrum.*, **19**, p. (1948).

(3) Meyer, K. P., Baldinger, E., and Huber, P. *H Phys. Acta*, **23**, p. 121 (1950).

(4) Bay Z. *Rev. Sci. Instrum.*, **22**, p. 387 (1951).

(5) De Benedetti, S., and Riching, H. J. *Rev. Sci. Instru* **23**, p. 37 (1952).

(6) Marshall, J. *Nucleonics*, **10** (3), p. 32 (1952).

(7) Wells, F. H. *Nucleonics*, **10** (4), p. 28 (1952).

(8) Bell, R. E., Graham, R. L., and Petch, H. E. *Can J. Phys.*, **30**, p. 35 (1952).

(9) Frank, W. J., Bandtel, K. C., Madey, R., and Mov B. J. *Phys. Rev.*, **94**, p. 1716 (1954).

(10) Chance, B. *Waveforms*, p. 244 (New York: McGr Hill Book Co. Inc., 1949).

(11) Ashmore, A., and Collinge, B. Private commun tion.

(12) Moody, N. F., MacLusky, J. R., and Deighton, M *Electronic Engng*, **24**, p. 214 (May 1952).

The effect of humidity on the stability of inductance standards

By G. H. Rayner, B.A., A.M.I.E.E., and L. H. Ford, M.Sc.(Eng.), A.M.I.E.E., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 23 *September*, 1955]

The N.P.L. sub-standard inductance coils have been found to vary in value with atmospheric humidity. The changes in inductance for a 10% increase in relative humidity range from $+0\cdot7$ part in 10^4 on a 100 μH coil to $-0\cdot25$ part in 10^4 on a 10000 μH coil. The changes may be partly explained by dimensional changes in the formers of the coils.

revious paper(1) by the authors described the stability of ous standards of mutual and self-inductance in the ession of the National Physical Laboratory; in it reference made to inductors covering the range 1 μH to 1 H that used as sub-standards of self-inductance. These coils now been in use for about ten years, and experience has gained of their stability; the estimate of 1 part in 10^4 ne change which is unlikely to be exceeded in a period of years for the coils of larger value, given in the previous er, has proved correct when temperature variations are wed for. There have been, however, fluctuations in the sured values of about this range and the measurements ribed below were undertaken to determine whether part ne observed changes were due to variations in atmospheric idity.

hese inductors are designed to have a small temperature ficient of inductance.(2) They are constructed with two checks of laminated paper Bakelite that support longinal members of loaded ebonite on which the coil is nd; the loaded ebonite has a larger thermal coefficient xpansion than the Bakelite and thereby compensates for hermal expansion of the latter. The values up to 100 μH single layer coils, those from 200 μH to 2 mH are multir coils on a small former and above 2 mH there are large i-layer coils. All the inductors are wound with ndraht wire.

METHODS OF MEASUREMENT

lf-inductors can be measured against the N.P.L. subdard mutual inductometer using the Campbell–Heaviside ge. The accuracy is greatest on inductors of 10000 μH, equal ratio resistance arms may be used—thus avoiding necessity for the measurement of the ratio—and the ctometer is used up to its maximum setting; the observaal accuracy of this measurement is 1 part in 10^6. The nal procedure at the N.P.L. is to measure the 10000 μH ctor in this way, and to obtain the values of the other ctors from it by successive comparisons on a Maxwell ctance ratio bridge; the observational accuracy of these parisons is 1 part in 10^5 or better.

this investigation the 10000 μH inductor was measured escribed above and each of the lower value inductors compared with one of a higher value which was sensibly tant over the period of the tests; the 20000 μH inductor measured directly against the inductometer with the pbell–Heaviside bridge modified to have a 2 : 1 ratio. he measurements were made at a frequency of 1000 c/s a temperature of 20° C.

ne desired value of atmospheric humidity was obtained lacing the inductor under test in an air-tight container a dish containing a saturated solution of an appropriate 3) Tests with a recording hygrometer showed that at moderate values the relative humidity within the container reached equilibrium within about twelve hours; at the highest relative humidity a longer time was required and it is possible that the nominal humidity was never quite achieved.

EXPERIMENTAL RESULTS

Three sizes of former are used in the manufacture of the complete set of inductors covering the range 1 μH to 1 H. From an examination of past calibrations and some preliminary exploratory tests it appeared that the behaviour of the inductors was largely dependent upon the type of former on which the coil was wound. It was decided, therefore, to select for extensive measurements one inductor with each type of former; the values were chosen to permit the highest accuracy to be obtained and were 10000, 2000 and 100 μH, the last two being the maximum values with each of the two smaller formers, while the first can be measured directly against the sub-standard mutual inductometer.

10000 μH inductor. Determinations of the inductance, in terms of the sub-standard inductometer, were made at intervals with the coil in an atmosphere of constant relative humidity, and in general were continued until the rate of change of inductance was less than 5 parts in 10^6 in a week. The solution in the container was then changed to give a new value of relative humidity and the process continued. The results obtained are given in Fig. 1; this shows the difference in inductance from the value finally obtained at 44% r.h., at various times from the commencement of the tests in the controlled atmospheres. It should be noted here that when the new solutions were inserted at nineteen days and thirty-one days a small quantity of freshly activated silica gel was also placed in the container to hasten the initial drying, as these measurements were part of the preliminary tests; it will be seen that as a consequence the initial rise of inductance is exceptionally rapid.

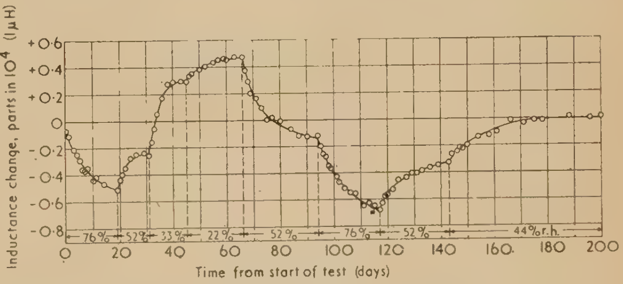


Fig. 1. Variation of inductance in a 10000 μH inductor with atmospheric relative humidity

Values at 300 days $+0\cdot08$, at 370 days $+0\cdot02$, and at 450 days $-0\cdot02$ parts in 10^4.

The value of the inductance could be read to 0·01 μH, i.e. 1 part in 10^6 and the tests were carried out in a temperature-controlled room; however, small variations of temperature occurred from day to day and since both the mutual inductometer and the inductor under test have temperature coefficients of about +1 part in 10^5 per 1° C, these temperature changes introduced a small uncertainty into the measurements. The values recorded in Fig. 1 have been corrected for a constant value of the resistance of the inductor as this, being observable within ±1 part in 4000, was found to be the best criterion of the inductor's temperature. The uncertainty in the temperature of the mutual inductometer was 0·1° C, and the combined uncertainty due to temperature was about 0·02 μH on the value of inductance; thus the overall limits of observational error on any measurement were about ±0·03 μH.

The stability of the sub-standard inductometer is such that the value at the 10 000 μH setting, in terms of the N.P.L. Primary Mutual Inductance Standard, did not change by more than 1 part in 10^6 between the calibration in January 1954 and that in January 1955, during which period most of the measurements were made. However, the possibility that some fluctuations in value may have occurred in the inductometer during the experiments cannot be completely excluded.

The results show clearly that a period of several weeks rather than days is required for the inductor to reach a stable value when maintained at a constant humidity; from an analysis of the results it is found that the change of inductance with time following a sudden increase of humidity is closely an exponential function having a time constant of about ten days. Assuming this, it is possible to compute the values of inductance that would ultimately be reached at the various humidities; it is then found that the inductance is linearly related to the relative humidity and decreases by 0·25 μH (0·25 parts in 10^4) for a 10% increase in relative humidity.

An inductor of this type that is kept in a room subject to the normal day to day fluctuations of humidity will show changes of inductance that depend upon the previous variations in the relative humidity. It is possible to obtain what may conveniently be termed the effective relative humidity from a knowledge of the time constant τ of the inductance variation with humidity, combined with a continuous record of the humidity; this effective humidity is the value of the steady humidity which would, if the inductor were in equilibrium with it, correspond to the inductance at any given time. The effective humidity R_e at a time T is obtained from the expression $R_e = \frac{1}{\tau}\int_0^{\infty} R \exp(-t/\tau)dt$, where R is the relative humidity at a time interval t before T; a simple way of computing R_e is given in the Appendix. In this way it is calculated that on the day the inductor was first placed in the container the effective relative humidity was 48%, although the actual humidity on that day was 57%; this gives a value of inductance that agrees within 3 parts in 10^6 with that recorded in Fig. 1, or regarded as an uncertainty in relative humidity it corresponds to 1%, which is about the accuracy of the recorded values of humidity.

The values obtained during the tests, when the inductor was maintained in closely controlled conditions, show that under steady conditions of temperature and humidity the inductance would remain remarkably constant. An attempt has been made to adjust the values previously obtained on this inductor to standard conditions of humidity and temperature; the fluctuations of the adjusted value range over about 0·4 μH, and are about half those of the observed values since 1950, when the room in which the inductor kept and the measurements made was equipped with the statically controlled heating.

2000 μH inductor. A restricted range of measuren showed that this inductor decreases in value by 0·0 when the humidity is raised from 33 to 66%; this corresp to −0·12 parts in 10^4 for a 10% rise in relative humi The time constant of these changes was between seven ten days.

100 μH inductor. This inductor was measured number of values of relative humidity in the range 2 86% and it was found that there was a linear chang inductance with humidity of +0·7 parts in 10^4 for each rise in relative humidity. The changes took place much rapidly than with the other inductors mentioned above the time constant was about ten hours; Fig. 2 shows

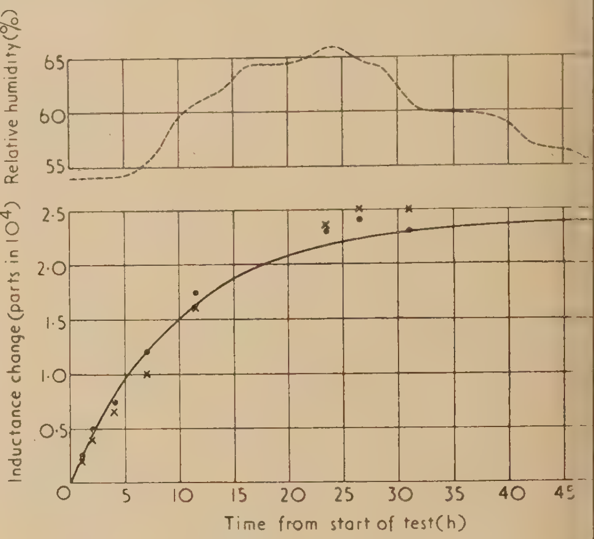


Fig. 2. Variation of inductance in a 100 μH induc after two weeks at 22% r.h.

——— = 2·4 [1 − exp (− t/10)] (t in hours).
× = observed results.
● = values adjusted for constant relative humic of 60%.
- - - - = measured relative humidity.

inductance changes of this inductor when it was expos a room of 54 to 66% r.h. after it had been kept for two w in an atmosphere at 22% r.h., the actual room humid also recorded in the figure and the observed value inductance have been adjusted for a constant room hum of 60%. An exponential curve with a time constant o hours is shown in addition.

Another 100 μH inductor of a recent, modified design found to change by +0·4 × 10^{-4} for a 10% rise in rel humidity.

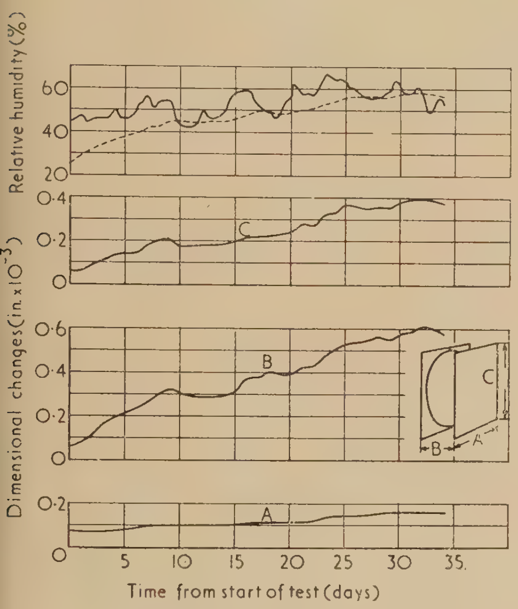
Inductors of other values. Several of the multi-l inductors from the smallest one of 200 μH to tha 100 000 μH were measured at two values of relative hum and changes of −0·1 to −0·15 × 10^{-4} for 10% ri relative humidity were obtained.

DIMENSIONAL CHANGES

In order to obtain more information on the cause o inductance changes—particularly in view of the diff behaviour of the single layer 100 μH inductor and th multi-layer inductors—observations were made on the and 2000 μH inductors of the changes in the overall nsions caused by a change in humidity. Each inductor kept in a container at 22% r.h. for a few days and was removed and set up in a measuring jig with dial gauges; were used to observe changes in the three main nsions. The gauges were divided 1/10 000 in. and ings to 1/10th of a division were attempted, but no great ficance can be attached to the last figure. The whole ratus was subject to the normal variations of humidity ng place in the room, which was temperature controlled; wance was made for any small variations of temperature.

ne 100 μH inductor has overall dimensions of 5 in. in direction; no significant changes were observed during riod of two days due to an increase in humidity from 55%.

ne 2000 μH inductor is $3\frac{1}{4}$ in. overall length, while the checks are 5 in. square. Fig. 3 shows the changes in the nsions of this inductor during a period of a month after as taken from the container at 22% r.h.; the changes are nite and are related approximately exponentially to the nidity, having a time constant of about five days; the ulated values of effective humidity assuming this time stant are also shown for comparison.



ig. 3. Dimensional changes in a 2000 μH inductor after eight days at 22% r.h.

Relative humidity
——— = measured
– – – – = calculated

DISCUSSION OF RESULTS AND CONCLUSIONS

he different behaviour of the 100 μH inductor from that ne others shows that two agencies are having an effect on properties. From the rapidity of the changes in the of the 100 μH inductor it is inferred that they are due superficial effect and it is possible that the silk binding ne litzendraht wire is responsible. The comparatively slow nges found in the larger multi-layer inductors are almost certainly due to dimensional changes in the formers upon which the coils are wound; this effect is likely to be present in the 100 μH inductor as well, but it is masked by the much larger and quicker inductance changes already noted. The larger inductors showed no indication of the rapid change found in the 100 μH inductor.

The slow rate at which the inductance responds to changes in humidity makes it more difficult to correct for day to day differences in humidity, than for such changes of temperature. While it is possible to allow for humidity differences if the precise effect of humidity on the inductance is known it is probable that these effects are of a more complex form than the simple exponential function assumed above and therefore the correction for humidity is only approximate. Also, the dependence of inductance on humidity has a bearing on the temperature coefficient of an inductor; if this is measured over a range of temperatures without regard to the relative humidity, the measurements at the higher temperatures will be made at lower humidities, and the effective humidity will depend upon the time for which the higher temperature has been maintained. The resulting temperature coefficient will be different from that obtained under conditions of constant relative humidity. As there is no direct relationship between the day to day temperature and humidity variations in an ordinary room it is necessary to allow for the two independently.

If the highest stability is required in an inductance standard of this type it should be maintained in an atmosphere of constant relative humidity and at a constant temperature. The results given in this paper indicate that an improvement of 10 to 1 can be realized in the stability under these conditions over that in an uncontrolled room. The improvement achieved with the 10000 μH inductor is even greater than this.

It is of interest to note that except on the 100 μH inductor the changes of inductance with relative humidity are about the same magnitude as the changes of capacitance in an air capacitor due to the change in permittivity of air: this is an increase of 0·2 in 10000 for a 10% rise in relative humidity. Furthermore, if the humidity variations are allowed for, the stability of some of the inductors on the largest formers is remarkable: for example, since 1946, when the inductors were obtained, all the calibrations on the 100000 μH inductor have been within a range of 0·3 parts in 10^4. A general comparison of the stability of these inductance standards with that of the N.P.L. standards of capacitance(4) shows that the inductors have a rather better stability.

ACKNOWLEDGEMENTS

The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

REFERENCES

(1) Rayner, G. H., and Ford, L. H. *J. Sci. Instrum.*, **27**, p. 19 (1950).

(2) Griffiths, W. H. F. *Wireless Eng*, **19**, p. 8 (1942).

(3) *N.P.L. Notes on Applied Science*, No. 4 (London: H.M. Stationery Office, 1953).

(4) Rayner, G. H., and Ford, L. H. *J. Sci. Instrum.*, **28**, p. 168 (1951).

APPENDIX

The evaluation of the effective relative humidity

The expression $R_e = \frac{1}{\tau}\int_0^\infty R \exp(-t/\tau)dt$ may easily be integrated numerically as follows. The function $\exp(-t/\tau)$ is obtained for various values of t and the first differences taken; these are multiplied by the mean humidity during the time intervals of the successive values of t and the sur the products gives R_e. It is not necessary that the tim shall be equally spaced, and it is convenient to select lo intervals as t increases. If R_e for a given time T has calculated in this way, the value of the effective hum R'_e, at a later time T' may be obtained from the expres $R'_e = R_e + (R - R_e)[1 - \exp(T' - T)/\tau]$ where R is relative humidity during the time T to T', provided th single, mean value of humidity may reasonably be taken this period.

Fundamental behaviour of sensitive springs

By Prof. R. TOMASCHEK, Ph.D., F.R.A.S., The British Petroleum Co., Ltd., Kirklington Hall, Nr. Newark, Nott

[*Paper first received* 18 *May, and in final form* 25 *July*, 1955]

It is shown that by extending a flat spiral spring by a force acting at one of its ends perpendicular or at an angle to its original winding plane, shapes of a special form, called serpent springs, can be obtained. Though capable of supporting relatively heavy loads, these springs respond under certain conditions to small changes in the loads by considerable lengthening and twisting. The conditions for obtaining such springs of high sensitivity and their fundamental behaviour are described.

When measuring very small variations of a force, or small forces in the presence of a relatively large one, by the proportional elastic deformation of a suitable element, very small displacements are superimposed on a very large original one.$^{(1)}$ This difficulty can be overcome to a certain degree by using a pre-stressed element, e.g. "zero" springs in the case of helical springs.$^{(2)}$ A second method consists in using "astatization" by combining the elastic element with another mechanical element (e.g. levers,$^{(2)}$ bifilar suspensions,$^{(3)}$ etc.) in such a way that an unstable region exists with theoretically infinite sensitivity.

When small instruments of high sensitivity are required, a single element instead of a combination is desirable. In the course of investigations into such possibilities a peculiar behaviour of spiral springs has been observed which is described in this paper. It is possible to obtain an elastic element the high angular sensitivity of which is independent of its size, and which has a shape suitable to application in a confined space.

1. BASIC EXPERIMENTS

(*a*) *Regions of increased sensitivity.* If a spiral spring, for example the main spring of a clock, is fixed at its inner end, the winding plane of the spring being horizontal, and a vertical force increasing in time is applied at its outer free end, say downwards by a weight, it uncoils in a way as shown in Figs. 4 and 7. The uncoiling is connected with lengthening and a twist of the lower end.

If h, the linear distance between the upper and lower end of the spring, or the positional angle α of the end is measured as a function of the applied force W, a behaviour as plotted in Fig. 1 for α can be observed. The analogous curves for h are quite similar (see Section 3). The slope of the $h = f(W)$ or $\alpha = f(W)$ curve is not constant, but is fairly steep in two regions. These are connected with a perceptible uncoiling of the lowest turn yet existing at this stage. The change in length Δh is measured in the direction of the force, and the change of the positional angle or twist $\Delta\alpha$ is measured as the projection of the twist of the end of the spring on a perpendicular to h.

Two sensitivities may be defined in the following way:

$$\text{angular sensitivity } \epsilon = \Delta\alpha/(\Delta W/W)$$

$$\text{and longitudinal sensitivity } \sigma = \Delta h/(\Delta W/W)$$

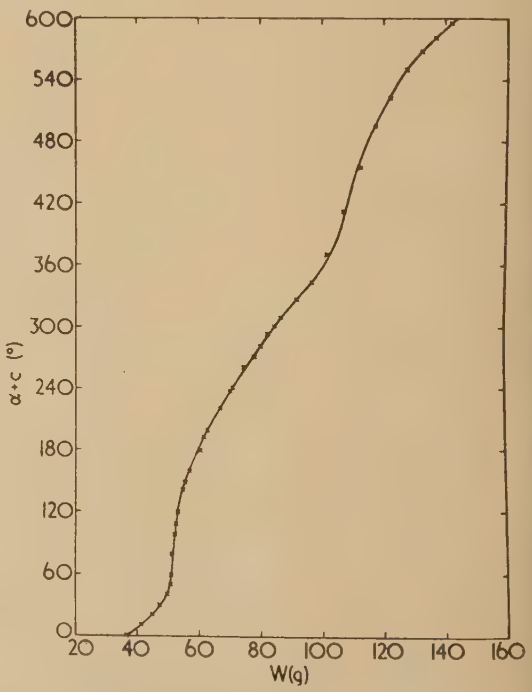
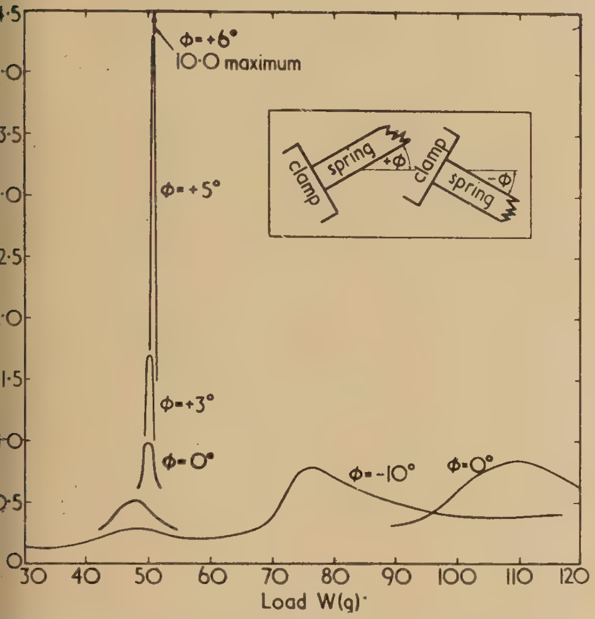


Fig. 1. Change of positional angle of loaded end typical *S*-type spring as a function of load W

As very small changes of force are considered here, expressions $\bar{\epsilon}$ and $\bar{\sigma}$ are used; these are measured in deg or centimetres for a change of acting force of one thousan s value. For changes in gravity this is very nearly valent to degrees or centimetres per gallon.

xpressing the measurements of Fig. 1 in terms of sensi- / we obtain maxima in two regions (as in Fig. 2). In following, the discussion is restricted almost exclusively he first maximum, as when operating there the spring is stressed than it is at subsequent maxima.

) *Influence of the inclination of the spring.* An interesting nomenon is observed when it is found possible to increase selective sensitivity by tilting the clamped end of the ng relative to the direction of the acting force. This can chieved in the following way.



ig. 2. Sensitivity $\bar{\epsilon}$ of typical *S*-type spring near axima for different inclination ϕ as a function of load W. Inset: Definition of $+\phi$ and $-\phi$

he long axis of the cross-section of the spring tape in the np remains vertical, but as the clamp is tilted round a zontal axis, the spring tape comes out of the clamp with ongitudinal axis elevated progressively. The angle of tilt ith the horizontal plane, as depicted in the inset of Fig. 2, ositive if the tilt is upwards and negative if it is down- ds (see Fig. 4 and Fig. 7, *ef* and *gh*). Fig. 2 shows that by ng from $\phi = 0°$ to $\phi = +6°$ the spring becomes ten s more sensitive. The weights corresponding to the ima vary only very little.

) *Existence of a critical region.* If the angle $+\phi$ is further eased, the sensitivity becomes extremely high at a certain cal value ϕ_{cr}, the weight having a value W_{cr}. Practically, sensitivity in this region is limited only by the stability he experimental arrangement. The behaviour in the ocritical" region, that is from $\phi = 0$ up to $\phi = \phi_{cr}$ is pletely reversible which means the curves are identical ncreasing or decreasing weight.

) *The supercritical region.* If $+\phi$ is further increased so $\phi > \phi_{cr}$, then at a certain weight which exceeds W_{cr}, spring suddenly jumps to a second state, which will be d the "lower" state. This transition is connected with len lengthening and twisting. If now the loading weight duced, length and deflexion show only small variations, suddenly, at a load which is less than W_{cr}, the spring jumps back to its former "upper" state. The area of the hysteresis loop is the larger, the more the angle of inclination exceeds its critical value ϕ_{cr}. Measurements of this type are shown in Fig. 3. In Fig. 3 (as in Fig. 6), the ordinate has been chosen increasing downwards. The reason for this is that as the lengthening is proportional to the twist, the curves give an immediate expression of the movement of the lower end of the spring.

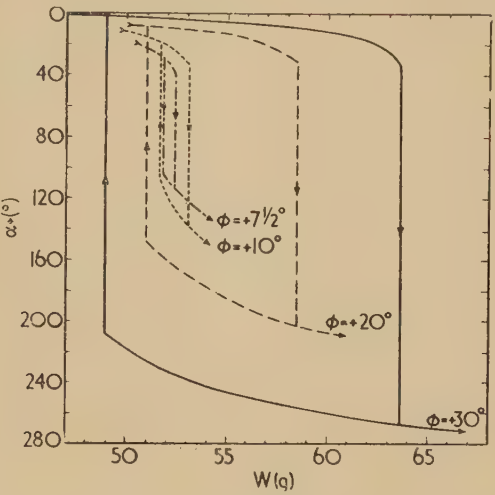
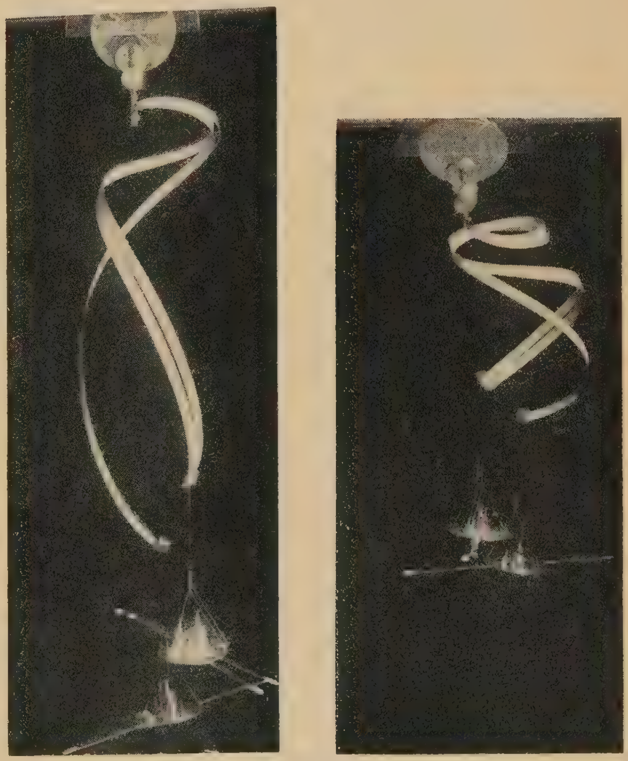


Fig. 3. α-*W*-curves for typical *S*-type spring in supercritical region

(*e*) *Critical state at negative values of ϕ.* If we incline the clamped end of the spring downwards, that is to negative



(*a*) (*b*)

Fig. 4. Shapes of typical *S*-type spring near the critical state with (*a*) positive and (*b*) negative inclination

values of ϕ, leaving again the long axis of the cross-section of the spring tape vertical, then, at first, the maximum becomes even flatter, as shown also in Fig. 2. But, with increasing $-\phi$, a second maximum develops at a different region of weights. On increasing ϕ to higher negative values again critical and supercritical regions develop.

Fig. 4 shows both critical states, namely for $+\phi$ and $-\phi$ in the reversible region. For the same spring, each in three different positions on the same film. The data are: steel spring, *S*-type, nearly two turns, blue annealed; height *a* 7 mm, width *b* 0·28 mm,

(*a*) $\phi = +\ 6°$, loads: 66·03 g, 66·23 g, 66·43 g.
(*b*) $\phi = -\ 37°$, loads: 31·13 g, 31·33 g, 31·53 g.

In general the behaviour for negative angles of ϕ is very similar to that at positive angles. However, under the operating conditions mentioned above, that is by changing the inclination in one plane only, sometimes only one of the critical states can be realized.

(*f*) *Definition.* The shape of the spring near its critical state resembles that of a lifting and uncoiling serpent. A spring in or near the critical conditions as described above will be called a "serpent spring."

2. CONDITIONS FOR THE EXISTENCE OF A SERPENT SPRING

(*a*) *Shape of cross-section of spring tape.* The cross-section has to be oblong, and the long axis has to be perpendicular to the plane of the undeformed spiral. Spirals wound in the plane of the long axis, so as to give planar spirals, do not display the serpent spring effect. Nor is it easily given by spirals where the ratio of length of cross-section (height) to thickness is much less than 10 : 1. This ratio at least is desirable, as otherwise the critical weights become too high and may surpass the elastic limit or even the breaking point. The ratio for the spirals mostly used in this investigation vary from 10 : 1 to 100 : 1. If the ratio is too high difficulties due to neighbouring windings touching each other often arise.

(*b*) *Material.* Generally the material should not be too soft nor too stiff as lasting deformation or fracture may occur; annealed steel springs, as used for clock springs, have proved very satisfactory for the primary investigations described here. The accuracy of the measurements is mainly determined by the variations of temperature. Experiments aiming at higher accuracy require materials of the Elinvar type, which yield springs of a very perfect temperature compensation. It seems possible to compensate for temperature effects also by unilaterally coated or bimetallic strips, but as Elinvar-type springs proved very satisfactory experiments were not extended far into this region.

The stability (lack of drift) seems to depend mainly on the stiffness of the materials. The hardness, as measured by one of the usual methods, is a good pointer in this direction.

(*c*) *Shape of the spiral*

(i) *Distance of turns.* A spiral shape with constant distance between the windings (*L*-type, equivalent to the outer windings of an Archimedean spiral) is quite convenient and has been used in the more accurate later measurements. In the first experiments, as described here, spirals with a nearly constant increase in distance between the windings (*S*-type) were used. The serpent spring effect does not seem to be very sensitive to slight irregularities of the spiral.

(ii) *Shape of turns.* The spirals need not necessarily circular shape. Elliptic and other forms of the spiral the effect, but pecularities may be expected. The inv gations reported here refer to circular spirals with relat small deviations from perfect shape.

(*d*) *Number of turns.* The number of turns of the unlo spiral seems limited only by problems of the windings touc when using the normal mode of winding and the ratic height to thickness required. Therefore, in these prelimi investigations five turns have rarely been exceeded. In to operate with as simple a shape as possible one and a turns, which is near the lower limit, have been used and three to four turns in order to investigate the influenc additional turns.

3. TWO NOTABLE FEATURES OF SERPENT SPRI

(*a*) *Linearity between twist and lengthening.* Having re to the complicated shape of a serpent spring it is surpr to find that there exists strict linearity between twis lengthening, even if the spring passes a maximum of ext sensitivity. Fig. 5 shows this for a spring of the *L*-type is the same spring as shown in Fig. 7.

This relation holds, in any case, within the range

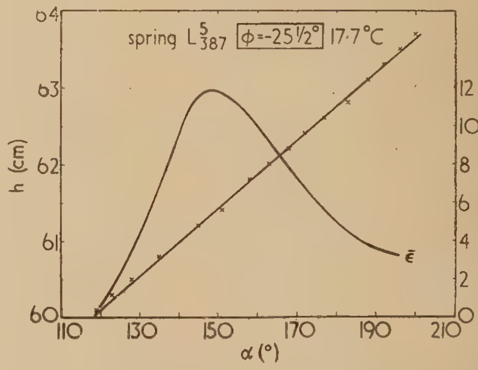


Fig. 5. Linearity of $h = f(\alpha)$ in the region of high sensitivity $\bar{\epsilon}$

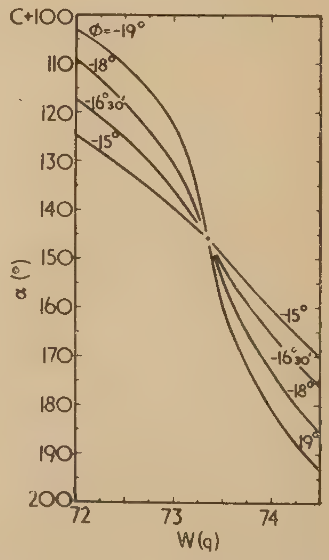


Fig. 6. α-*W*-curves for a spring in subcritical region

itive region. Over a much wider range the slope of the ight lines, giving the connexion between length and angle eflexion, changes fairly suddenly at certain regions which not identical with the selective sensitive regions but ede them. A small deviation from the linear behaviour ns to exist in certain cases, but even then it is negligible in the range of the critical region.

) *Existence of a singular shape.* Another characteristic ure of the serpent spring is as follows: if the plane of nation is kept constant, as it has been throughout the eriments described above, then the $\alpha = f(W)$ or $h = f(W)$ ves intersect all in one point, which is independent of the ination ϕ. Fig. 6 shows the results of measurements ch have been taken with increased accuracy to investigate question.

his behaviour indicates that for a certain load the length position angle (and to a certain extent the shape of the ng) remain unaltered and independent of the inclination of clamped end within a considerable range.

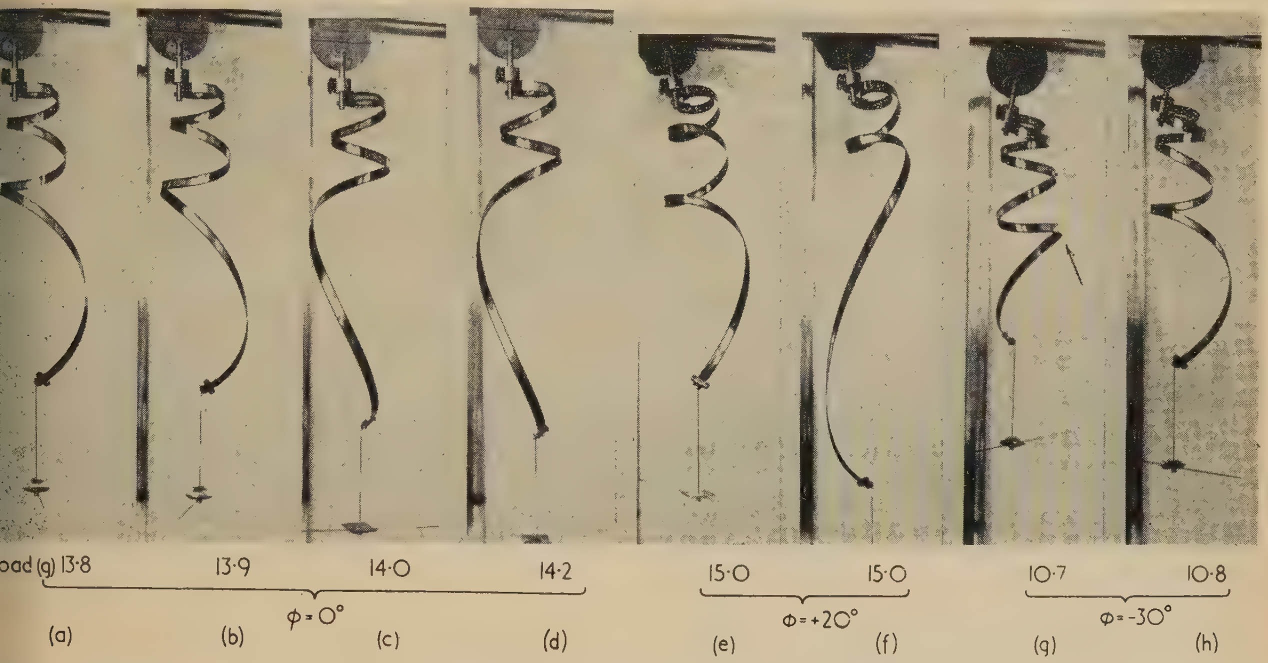


Fig. 7. Behaviour of typical *L*-type spring with three extended turns

. THE CHARACTERISTIC CHANGES OF SHAPE FOR SPRINGS WITH SEVERAL TURNS

ig. 7 shows the different shapes of a serpent spring eloping out of an L-type spiral spring made of spring , annealed blue; 0·005 in., height 0·387 in. For the surements reproduced in Fig. 7 only the outer three turns used; the innermost part is out of action. In all these es the clamped upper end of the spring is kept with its axis vertical.

The left side of Fig. 7 shows four stages (*a*, *b*, *c*, *d*) for $\phi = 0°$ (clamped end horizontal) at increased loading near the sensitive region which lies between 13·9 and 14·0 g at this inclination, which is not far from the critical angle of $+2°$ for positive inclination. Fig. 7 (*e*, *f*) show the two shapes which exist in the supercritical region at the same weight of 15·0 g at an inclination of $\phi = +20°$ which is 18° above the critical angle. Fig. 7 (*g*, *h*) show the transformation of shape when passing the sensitive region at nearly critical negative inclination of $\phi = -30°$. Fig. 7 (*g*, *h*) pictures correspond to (*b*) and (*c*) at positive inclination. But (*g*) and (*h*) show much more clearly the straightening out of one winding (marked by an arrow) as the characteristic feature of the sensitive behaviour. This leads to an understanding of the underlying mechanisms as will be shown in a subsequent paper.

ACKNOWLEDGEMENT

I wish to thank the Chairman of The British Petroleum Co. Ltd. for kind permission to publish this note.

REFERENCES

(1) For application of helical springs, see TOMASCHEK, R., and SCHAFFERNICHT, W. *Astron. Nachr.*, **244**, No. 5844 (1932); WYKOFF, R. D., *Geophysics*, **6**, p. 14 (1941).

(2) LA COSTE, L. J. B., and ROMBERG, A. U.S. Patent No. 2,293,437 (1942).

(3) TOMASCHEK, R., and SCHAFFERNICHT, W. *Ann. Phys.* [*Leipzig*], **15**, p. 767 (1932).

Laboratory and workshop notes

A simple universal X-ray camera stand

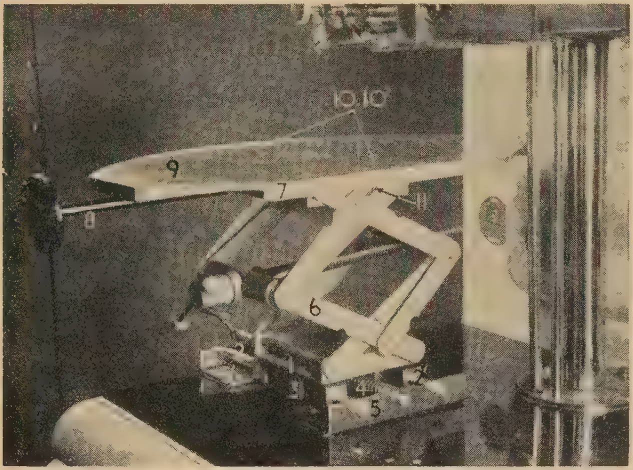
By M. D. Karkhanavala, Ph.D., Chemistry Division, Atomic Energy Establishment, Bombay, India

[*Note received* 28 *June*, 1955]

A simple stand has been constructed which permits the use of cameras of both standard and special designs as well as the Philips wide-angle goniometer with the Raymax X-ray crystallography unit.

The essential features of this stand are: (*a*) easy and continuous motion in the three translational directions (x, y and z), and (*b*) rotation in the horizontal (x, y) plane. Wide latitude is provided in the vertical direction so that the collimating system of any kind of camera can be alined with the window. Sufficient traverse is also provided in each of the other two directions, so that the camera can be moved (*a*) towards or away from the window, and (*b*) across the window. This last motion coupled with the vertical adjustment is very essential in locating the most intense part of the beam.

The stand, as mounted on the Raymax unit, is shown in the figure. It consists of a carriage (1) sliding on two rods (2, 2′) $3\frac{3}{4}$ in. apart, through six lugs (3), three on either side and welded to the bottom of the carriage. The sliding motion is achieved by a square-threaded screw (4) fixed in position at the two ends by the angles (5, 5′). Rigidly attached to this carriage is a jack (6), which allows ten inches of vertical motion. The two frames of the jack are placed 6 in. apart to ensure good stability. To the top of this jack is attached a platform (7 × 9 in.) through another square-threaded screw (8) permitting a cross movement of the platform by about $1\frac{1}{2}$ in. A wide aluminium base (9) rests on the platform and is secured in position through two screws (10, 10′). These screws move freely in two circumferential slots provided in the platform (7) and are fixed in any desired position by tightening the wing nuts (11) which are underneath the platform (7) and barely visible in the figure. The circumferential slots are long enough to provide a rotation through ±5° of the camera base.



X-ray camera stand

Two stands, one for the right-hand and one for the left-hand port, could be fixed to the main base plate of the Raymax unit by means of bolts and nuts in the usual way.

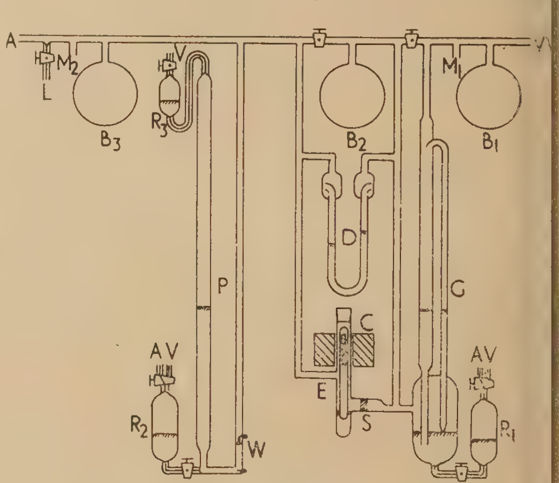
A sensitive manostat

By H. Tompa, Ing., Dr. techn., F.Inst.P.,* Courtaul
Ltd., Maidenhead, Berks.

[*Note first received* 6 *June, and in final form* 22 *July*, 1955]

A glass manostat is described which is capable of contro the pressure in an apparatus to better than 0·05 mr mercury at any pressure between 0 and 760 mm of mer This is achieved by the operation of a "valve," consisti a disk of sintered glass sealed into a tube, through whic apparatus is connected to a reservoir at lower pressure which is closed by letting mercury cover its high-pressure The essential point is that, though there is a pressure diffe across the sintered glass disk, mercury will not flow thr it if the pressure difference is kept below a critical determined by the capillary depression of mercury, i.e size of the pores of the disk. This design therefore avoid difficulties connected with the construction and operati valves containing moving parts.†

The figure shows the complete layout of the manosta vacuum pump is connected at V to the vacuum sid Gilmont–Othmer type pressure regulator G,‡ which the pressure on the low pressure side of the sintered disk S of the valve E approximately constant; the othe of S is joined to the apparatus at A. The pressure is me in the narrow limb of the mercury manometer P, which contains two sealed-in tungsten contacts W; the wider, limb of P is kept at a permanent vacuum by mercury occasionally to flow into R_3. The amoun mercury in P is adjusted from R_2 so that the mercury reaches the upper contact W in the narrow limb whe apparatus is at the desired pressure, the amount in adjusted from R_1 so that the pressure difference across measured by D, is well below the critical value. Ir apparatus used by the author S was a grade 2 sintered



Layout of manostat

---

[*] Now at European Research Associates, Brussels, Belgiun

[†] See, for example, Clow, A., and Shand, G. *J. Sci. Ins* **16**, p. 354 (1939); Oliver, G. D., and Bickford, W. G. *Rev Instrum.*, **16**, p. 130 (1945).

[‡] Gilmont, R., and Othmer, D. F. *Industr. Engng* (*Analyt. Ed.*), **15**, p. 641 (1943).

which required about 300 mm of mercury pressure to -mercury flowing through it; it was found that a sure difference of 100 mm of mercury across *S* was more sufficient for satisfactory operation of the manostat, and value was never exceeded. As shown in Fig. 1, *D* was l with splash heads, so that it could act as a safety de- by allowing excessive pressure differences across *S* to lize long before they reached the critical value. Mano-rs could be attached to M_1 and M_2 if desired; B_1, B_2 B_3 are ballast flasks, *A* and *V* are connexions to osphere and the vacuum pump.

hen the pressure in the apparatus increases above its set e, contact at *W* is broken; the limb containing *W* is much ower than the other limb so that most of the change in level of the mercury takes place there. Breaking the act at *W* causes the coil *C* to be energized by the anode ent of a gas-filled triode, and the plunger in *E*, which has on core sealed in its top half, is lifted. The mercury level drops, uncovering *S*, and gas flows from the apparatus B_2. As the pressure in the apparatus drops, the mercury e narrow limb of *P* rises and contact is made at *W*; the ent through *C* stops and the plunger drops, displacing gh mercury to raise its level above the top of the side containing *S* and shutting off the flow. It was found ntageous for smooth control to maintain a small leak at that the plunger was never allowed to rest long.

the apparatus used by the author the diameter of *S* 10 mm and such disks, sealed into glass tubes, are mercially available. The plunger was 150 mm long, n in outside diameter and weighed 45 g, the inside eter of *E* was about 11 mm. None of the other ensions are in any way critical.

e manostat was used for long periods to keep the sure of boiling liquids for vapour baths constant. The sure fluctuations were well below 0·05 mm of mercury, g temperature control to better than 0·01° C.

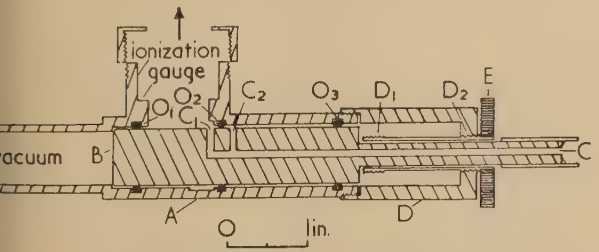
A simple air lock for ionization gauges

y C. Barrow, Department of Physics, University of Birmingham

[*Note received* 25 *July*, 1955]

arge vacuum systems, such as that of the Birmingham on synchrotron, the ability to fit and remove ionization ges without losing the vacuum presents an obvious ntage. This note describes a compact and simply tructed valve which makes this possible.

he device is shown in the figure. It consists essentially brass tube *A* which protrudes from the vacuum system, contains a solid rod *B* ¾ in. in diameter which slides in it. Three O-rings (O_1, O_2 and O_3) are placed inside the tube, one (O_3) at the end and the other two (O_1, O_2) on each side of a branch tube which connects to the ionization gauge. When the rod is almost fully inserted the innermost O-ring O_1 makes a seal between the ionization gauge and the vacuum system. Further insertion brings the rod to a stop and also connects the ionization gauge to the atmosphere through a hole *C* down the centre of the rod. Following replacement of the ionization gauge, the air lock is exhausted by a roughing pump, whence the rod is withdrawn until the gauge connects fully with the system.



Diagrammatic view of air lock

Two pump-out channels through the rod (C_1 and C_2) are required so that the small quantity of air between the outermost O-rings O_2 and O_3 is evacuated at the same time as the air-lock. This ensures that as the rod is withdrawn no air enters the ionization gauge as the innermost hole C_1 passes the middle O-ring O_2. The pump-out channels permit evacuation of the double O-ring seal formed between O_2 and O_3 when the rod is fully withdrawn. Screw threads D_1 and D_2 are provided to hold the rod in and out by union with the collar *D*, which threads on to the tube *A*. The threads and the knurled screw *E* used to move the rod are free to rotate about it so that the rod and the pump-out tube on its end do not rotate.

A portable β-γ radiation monitor

By B. W. Emmerson and S. P. Newbery, Institute of Cancer Research, Royal Cancer Hospital, London, S.W.3

[*Note received* 21 *July*, 1955]

For rapid surveys and contamination monitoring in hospitals employing radioactive isotopes in the treatment of patients, a light-weight portable instrument that is simple to use, which has a long battery life and requires negligible maintenance is most desirable.* An instrument incorporating these main features has been developed at this hospital and has performed in a satisfactory manner with continual daily use over the past twelve months.

A halogen quenched Geiger–Müller tube (type EWG5H by Twentieth Century Electronics Ltd.) is used as the detector for the ionizing radiation, a 15 mg glass end window allowing response to both β- and γ-energies. The extra high tension voltage is determined by the mid-plateau voltage of the Geiger–Müller tube and is of the order of 400 V ± 40 V. A cold cathode discharge valve (type GK33 by Ferranti Ltd.) and its associated circuit is used to produce a visual as well as an audible indication of the radioactivity being detected by the Geiger–Müller tube. The type GK33 valve requires an h.t. supply of 135 V, this being obtained from three "hearing aid" 45 V batteries. The e.h.t. supply to the type EWG5H tube is obtained from a miniature type 300 V battery in series with the 135 V h.t. supply. Thus an e.h.t. supply of 435 V is obtained, which, by varying the tap from the negative terminal of the 300 V battery can be set at an alternative voltage of 390 V, the actual setting depending on the mid-plateau voltage of the EWG5H tube.

In the circuit diagram (Fig. 1) a positive pulse due to the discharge of the EWG5H tube (GM_1) is fed to the grid of the GK33 valve (V_1). This initiates the main anode-to-cathode discharge causing the valve to conduct, the potential across it falling to approximately 70 V. The remaining supply voltage is dropped across the primary of the loudspeaker winding T_1, and the cathode time constant circuit R_2, C_2. The meter will indicate the current flow through the valve whilst the loudspeaker will reproduce an audible "click." The current drawn by the EWG5H tube is limited to a maximum of approximately 5 μA due to the high impedance of W_3 under these conditions.

---

* Franklin, E., and Loosemore, W. R. *Proc. Instn Elect. Engrs*, **98**, p. 237 (1951).

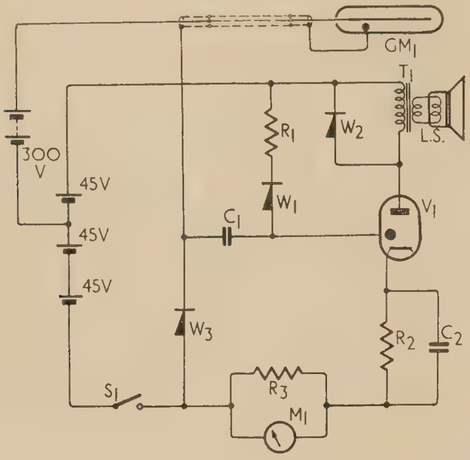


Fig. 1. Circuit diagram of portable β–γ monitor

R_1 = 10 MΩ, $\frac{1}{4}$ W
R_2 = 470 kΩ, $\frac{1}{4}$ W
R_3 = 1·8 kΩ, $\frac{1}{4}$ W

C_1 = 1000 pF, 500 V
C_2 = 0·02 μF, 500 V

W_1 = Unistor type Q3/3
W_2, W_3 = Unistor type Q8/3

T_1 = speaker transformer

L.S. = $2\frac{1}{2}$ in. diameter loudspeaker

V_1 = Ferranti GK33
GM_1 = Twentieth Century EWG5H or Mullard MX108
M_1 = 50 μA (moving coil)
S_1 = Press on-off (single-pole)

After the condenser C_2 has charged to approximately 65 V, the valve will no longer maintain the anode-to-cathode discharge and ceases to conduct, C_2 then discharging through R_2, this voltage falling to approximately zero after 47 ms (5 R_2C_2). This procedure is repeated for each pulse received at the trigger grid of the GK33 valve.

Fig. 2 shows the relationship obtained between dose rate (mr/hour) in free space from a radium needle of 2 mg with 0·5 mm platinum screen, and meter reading in microamperes, with four instruments of the type described, a full scale deflexion representing approximately 6·5 mr/hour. Although an accurate calibration of this form of instrument wa envisaged, its intended use being that of an indicative d the calibration has been found to hold over the twelve m of use. Very little statistical spread was found betwee of the four sets of readings (Fig. 2).

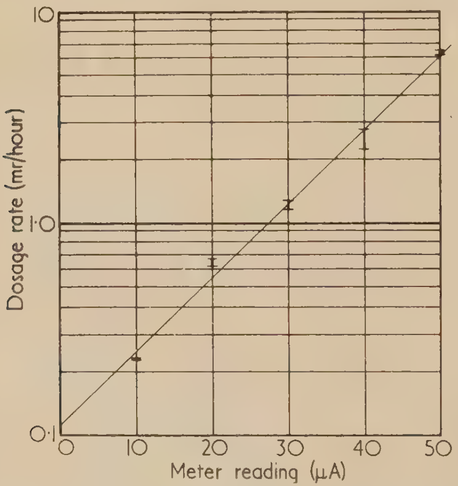


Fig. 2. Relationship between meter reading (μA) and dose rate in free space from a 2 mg radium needle with 0·5 mm platinum screen, for four monitor units

The type EWG5H tube can be replaced by either th G5H γ-response tube, or the type ML2 liquid counter without circuit alterations, thus making the instr much more versatile as a monitor. Fig. 3 shows a p

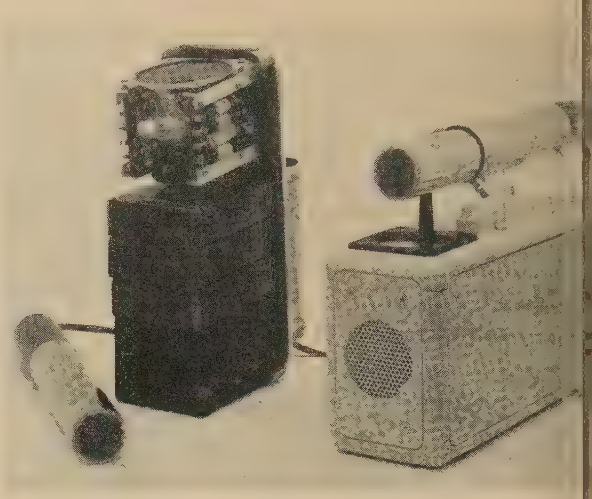


Fig. 3. Internal and external construction of fin instrument

graph of the finished instrument, the total weight 2·8 kg when complete. Both the type GK33 and EW tubes have a very long working life, whilst the batteries have all given much better than the manufacturer's shelf life.

A simple interval timer

By M. T. LILBURNE, M.Sc.,[*] and D. SHIPLEY, Phy
Department, Canterbury University College, Chr
church, New Zealand

[*Note received* 12 *October*, 1955]

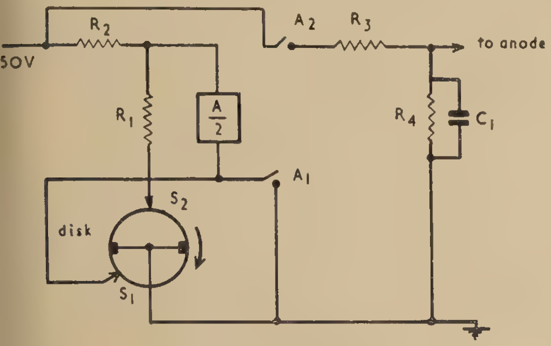
Occasionally there arises a need, for example when pulse counting circuits, for switches to be operated at acc time intervals. The interval timer here described has used to time periods of the order of 1 min to an accura at least $\frac{1}{10}$ s and can easily be adapted to time intervals 30 s up to 5 min with about the same accuracy.

A Perspex disk having two small copper inserts set metrically opposite in the edge was machined down to diameter. The disk was mounted on the drive-shaft mains-operated synchronous motor (by Sangamo–W Ltd.), the speed of which was 1 rev/3 min. The inserts electrically connected to the earthed motor shaft and brushes, set in appropriate positions, touched the edge disk lightly, forming S_1 and S_2 (see figure). The mo operation is as follows: when an insert is touched by the of S_1, the relay is closed and held by A_1. A Post Office 3000 relay with a 2000 Ω coil was actually used. This i ues to travel to the second brush S_2 and, when contact le here, the greater part of the relay current is shorted gh R_1 and hence the relay opens. Shortly after, the l insert repeats this cycle.

---

[*] Now at Admiralty Research Laboratory, Teddin Middlesex.

the particular purpose for which it was designed this vas placed between the pulse shaper and the Potter



Circuit of timer

$R_1 = 500\ \Omega$
$R_2 = 20\ \text{k}\Omega$
$R_3 = 5\ \text{k}\Omega$
$R_4 = 100\ \text{k}\Omega$
$C_1 = 0{\cdot}01\ \mu\text{F}$

of ten used in conjunction with a Geiger counter rometer.[*] The spare relay contact A_2 being used to n the high tension voltage of the final valve of the pulse r unit. R_3 and C_1 give an exponential voltage rise when oses and R_4 discharges C_1 when A_2 opens, thus effectively ing spurious pulses being recorded due to the operation e timer.

e interval timed can be altered by shifting one of the es or by using a different speed motor. It will be noticed the motor is operating under constant load conditions hat the unit does not require resetting. This eliminates of the disadvantages of using simple mechanical timers e cam type. Since the unit depends on a factor beyond operator's control, namely, the mains frequency, par- r care must be taken when the interval timed is greater one minute. The use of the timer was therefore confined f peak-load periods.

Rogers, J. L. and Chalklin, F. C. *Proc. Phys. Soc. on]* B, **67**, p. 348 (1954).

four-point probe apparatus for measuring resistivity

D. B. Gasson, Research Laboratory, Associated Electrical Industries, Ltd., Aldermaston, Berks.

[*Note received* 23 *September*, 1955]

ur-probe apparatus with a probe spacing of 1 mm and num surface leakage path of 1 cm has been developed neasuring resistivities of semiconducting materials.

e work head of the apparatus (Fig. 1) consists of four e holders mounted at approximately 90° to each other projecting radially inwards towards the centre of a hole in a ¼ in. thick Perspex hinged arm. Each probe er (Fig. 2) consists of a ¼ in. cube brass mounting block nich is soldered a 0·030 in. thick L-shaped brass plate. ne end of the brass plate is soldered a ½ in. length of 1 size stainless steel hypodermic tubing in which is ed a suitably sized steel sewing needle. The needle is ened to ¾ in. long and a 40° included-angle point ground on it. The needle is sprung by a length of 0·020 in. spring steel wire, one end of which is held in a hole in the mounting block by means of a small wedge and the free end is ground each side to fit loosely into the eye of the needle. The four probe holders are mounted on the Perspex arm so that the four points lie on a straight line with a spacing of 1 mm between each point.

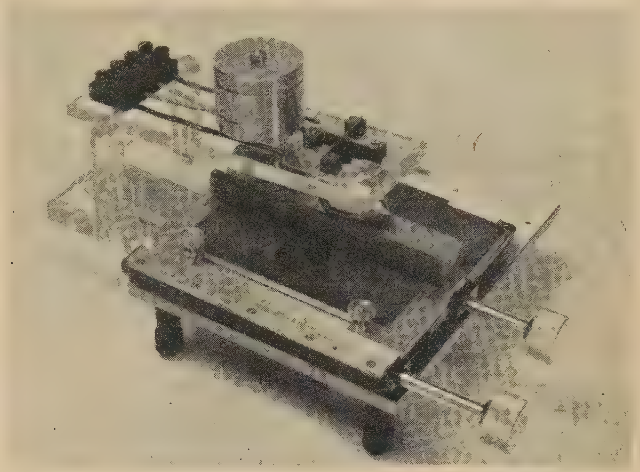


Fig. 1. General view of four-probe apparatus

The work head is then fixed to an adjustable microscope stage on which the specimen is mounted.

To make a resistivity measurement, the points are loaded on to the specimen by means of weights attached to the arm, giving approximately 50 g loading to each point.

Current in the range 1 to 5 mA is passed through the outer points and the voltage across the inner points is measured by normal potentiometric methods. The resistivity is thus $\rho = c.2\pi s(V/I)$ for the probe arrangement just described, where ρ is the resistivity, s the point spacing, V the voltage and I the current. Values for the factor c, which correct for finite specimen dimensions using four probes in line, have been published.[*]

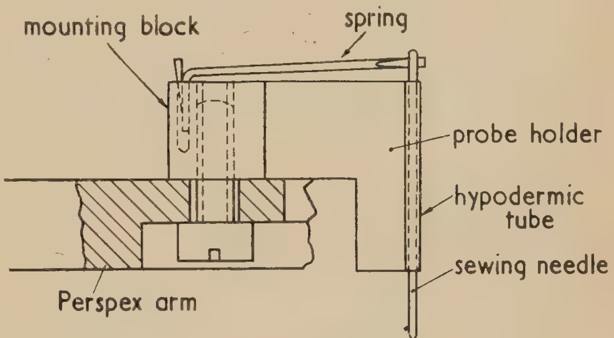


Fig. 2. Probe holder

It has been found that the most satisfactory surface treatment of the specimen to be tested is to grind the surface, wash and dry. In the case of material which has been cut, the sawn surface is satisfactory without further treatment.

Thanks are due to Dr. T. E. Allibone, and the Admiralty, for permission to publish this note.

---

[*] Uhlir, A., Jr. *Bell Syst. Tech. J.*, **34**, p. 105 (1955).

Correspondence

Errors in the A.S.T.M. Index of X-ray powder diffraction patterns

Early in 1953 the X-Ray Analysis Group of The Institute of Physics published(1,2) a request that A. J. C. Wilson should be notified of any errors which had been found in the A.S.T.M. Index of X-ray powder diffraction patterns. Over a hundred errors and comments have now been collected from twenty-six different sources. While it is expected that these will eventually be incorporated in the Index, it is thought advisable that they should be published now, so that regular users of the Index may be made aware of them earlier than would otherwise be the case. Some of the corrections, which were received soon after the original request for them, have already been incorporated in the set of Index cards issued in 1954, but are included for the benefit of those who possess only earlier sets.* Such corrections are appropriately indicated in the main table of errors. The various types of error which have been reported, and the percentage of the total represented by each type, are shown in the following table.

Analysis of errors

Type of error	*Percentage of total*
Incorrect naming or identification of substances (especially minerals)	22
Incorrect crystal structure, space group, or cell parameters	18
Incorrect or absent spacings or intensities	16
Misprints, including transcription errors from earlier cards, spelling mistakes, and omissions from the indexes to each set of cards	11
Incorrect structural or chemical formulae	9
Radiation given incorrectly	8†
Extraneous lines and specimen impurity	5
Loss of important lines by camera cut-off	5
Disagreement between cards	3
References given incorrectly	3

† The figure given here is probably not a true reflexion of the state of the Index. It is believed that there are many errors of this type that have not been notified, particularly in the First Supplement.

It will be observed that errors in actual powder patterns and in crystallographic data together make up 34% of the total, while errors in chemical formulae and mineral nomenclature, and misprints of varying importance, supply 42%. It is perhaps reassuring to note that camera cut-off does not appear to have introduced a serious source of error, and that few incorrect references have been reported.

The distribution of the errors among substances of various types is shown below:

	Inorganic			
Nature of substance	*Minerals*	*Non-minerals (except metals)*	*Metals*	*Organic*
Percentage of total errors	50	27	7‡	16

‡ Including nitrides, etc., of metallurgical interest.

The full list of corrections is too long for publication but will be circulated to members of the X-Ray An Group of The Institute of Physics and to those who purchased copies of the Index through the Institute; c who would find the list useful are invited to apply for a to one of the authors or to The Institute of Physics. I list the substances appear in alphabetical order. In the two columns of the list the reference numbers of the in the A.S.T.M. Index are given for each set in whic error occurs. The name of the substance follows, and a brief summary of the correction or comment as rec by the authors, whose occasional additional comment added in square brackets. The source of the correcti comment is indicated by a number which refers to the l acknowledgements.

The introduction into the Index of data obtained counter diffractometers has given rise to discrepancies w though perhaps not strictly errors, should certainly be po out here. An example(3) will indicate their nature.

The five strongest lines of the calcite pattern are:

(dÅ)	3·035	2·285	2·095	1·913
I/I_1 (camera, visual)	100	60	60	70
I/I_1 (counter)	100	18	18	17

Replacing the photographic pattern by the diffracto pattern, as recommended in the fifth set of A.S.T.M. c thus introduces different second- and third-stronges Such discrepancies frequently arise from the fact tha transparency factor (better, though less correctly, know the absorption factor) is constant at μ^{-1} for the flat specimen used in the diffractometer, but increases r rapidly with θ for the cylindrical rod used in powder ca

Since the use of counter data in conjunction with pa obtained with a camera, and *vice versa*, might lea difficulties in identification because of this effect, elimination of good camera data from the Index in f of counter data appears to be premature except whe three strongest lines of the two patterns agree. An exa tion of the eliminations recommended in the fifth s cards shows that some ninety substances (representing more cards) show disagreements of the kind under discu and that for about sixty of these the spacings of the strongest lines, as well as their intensities, differ in the ca and diffractometer data. A detailed list of these subst has been prepared, and is to be made available in the way as the list described above. It should also be notec it is not always indicated on a card that the data have obtained with a diffractometer; such cards are appropr indicated in the list.

The authors acknowledge with gratitude the assistan the organizations and individuals who have supplie information from which the full list of corrections has compiled. Their names are given at the end of the list.

Viriamu Jones Laboratory,
University College, Cardiff.

J. W. Hughes
Isabel E. Lewis
A. J. C. Wilson

REFERENCES

(1) *J. Sci. Instrum.*, **30**, p. 64 (1953).
(2) *Brit. J. Appl. Phys.*, **4**, p. 32 (1953).
(3) Whittaker, E. J. W. Private communication.

---

* About 600 correction cards are included in the sixth set of cards, but there is practically no overlap between the corrections noted in our list and those incorporated in the sixth set; the compilations are independent.

New instruments, materials and tools

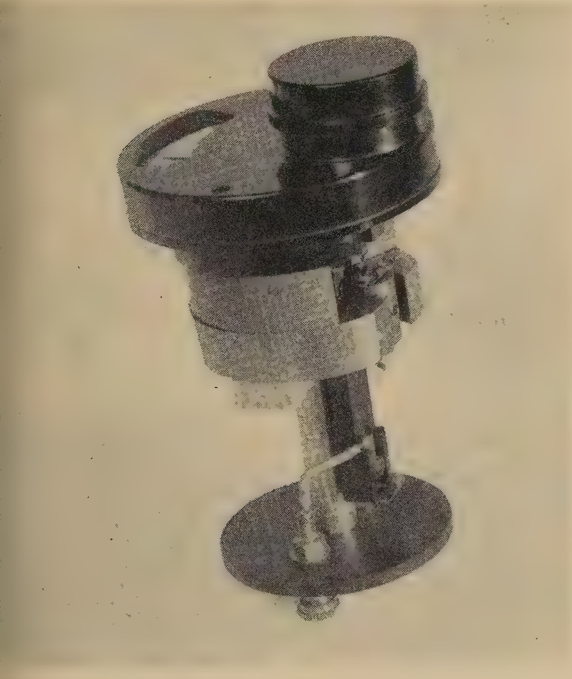
Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ucts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

romanipulator. American Optical, Export Sales, South- idge, Mass., U.S.A.

 the A.O. micromanipulator up to four different otools can be placed in the microscope field at the same and any selected pair of these can be used simultaneously e the other pair are readily available. Control of the otools in all directions is accomplished by a pair of joy s. A gain control allows adjustments of sensitivity to nade. The microtools are held in magnetic tool chucks the massive common base assures rigidity. There are noving parts to wear out and no glass or rubber parts to ace since the tool movements are effected by the thermal nsion of electrically heated wires.

anometers for instrument mounting. Doran Instrument Co. Ltd., Stroud, Gloucester.

 pointer and reflecting types of galvanometer are now lable for instrument mounting. The reflecting type anometer was originally designed to form part of a pact, self-contained unit in potentiometric apparatus. moving system comprises a formerless coil wound with -magnetic wire and held between the poles of a cobalt net by phosphor-bronze or cadmium-copper suspension . An insulated rotatable head is provided for zero stment. This type of galvanometer can be supplied with resistances of 18, 50 or 250 Ω, the current sensitivities /μA at 1 m) being 100, 150 and 300 respectively. The mped period in each case is 0·75 s.



Pointer galvanometer for instrument mounting

e pointer type galvanometer shown in the figure has a marked with 10–0–10 divisions, each division representing 1·5 mm at the pointer tip. The galvanometer is fitted in a metal tube $2\frac{1}{16}$ in. diameter and is primarily intended for panel mounting, the overall projection above the panel being $1\frac{3}{8}$ in. This model is available with coil resistances of 10, 30 and 250 Ω, the current sensitivities being approximately 0·6, 1, 6·6 div/μA, the undamped period being 1 s for the lowest resistance coil and 2 s for the others. A dual purpose combined pointer and mirror galvanometer is also manufactured consisting of essentially the same type of movement mounted in a circular metal case for bench use.

An improvement to a polarograph. Cambridge Instrument Co. Ltd., 13 Grosvenor Place, London, S.W.1.

The Univector polarograph unit is an accessory for use with this firm's pen-writing polarograph and enables a pure alternating voltage to be superimposed on the standard static voltage applied to the Heyrovsky mercury dropping system. This produces polarograms that are of greater sensitivity and more simple to resolve than the ordinary step polarogram. With this attachment the polarograms are automatically analysed and phase selected so that the records produced are of a simple form and require only one linear measurement to determine the concentration of the elements under test. The record pattern does not follow the customary step formation but rises from the base line to a height that is a direct linear function of the concentration of the element, after which it returns to the base line which is always at zero current.

The makers state that the sensitivity of a polarogram when using the Univector unit may be as great as twenty times that of a standard step polarogram, enabling detection of many substances to be made down to concentrations of 0·1 mg/l. A concentration of 1 mg/l. can be determined with an accuracy of 5% and concentrations of 10 mg/l. can be dealt with in ordinary routine measurements as compared with the 100 mg/l. concentration that is usual in step polarography. The measurements are less affected by dissolved oxygen thus saving time in gas purging.

Among other advantages claimed for the Univector method is that the sensitivity of the reaction depends upon the nature of the electrolyte but not normally upon its concentration, so that substances having close reduction potentials can be adequately separated by using a correctly selected electrolyte. This also assists the measurement of alloy constituents which can be determined without prior chemical separation.

Although the unit is primarily designed for use with the Cambridge pen-writing polarograph to which it may be attached without any modification, it may also be employed with Cambridge photographic polarographs and voltamoscopes by a small alteration in their circuits.

The Univector attachment is simple to operate, having only one control that is normally used, this being a zero compensator which gives a horizontal base line at higher sensitivities. At low sensitivities this control need not be employed. The attachment may be used to obtain both types of curve by the simple use of a selector switch fitted to the unit.

The unit operates from a single-phase alternating voltage supply and has a fixed frequency oscillator (not 50 c/s), thus making it independent of normal mains variations and eliminating interference and "pick up" from 50 c/s mains.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: R. T. W. Bingham, C. G. Cannon, A. H. Cockett, J. H. Davis, P. Hatfield, O. S. Heavens, G. M. Lewis, D. G. Marshall, G. B. Townsend.

Associates: E. W. V. Acton, T. S. Ainsworth, R. G. C. Arridge, A. J. F. Banks, R. W. Bicknell, H. Bridge, G. Brook, W. R. Caff, P. E. Ciddor, A. C. Copisarow, G. T. Davis, L. J. Davies, R. D. P. Davies, N. Dickinson, A. Dudley, T. P. Flanagan, K. G. W. J. Forshaw, W. Gemmell, J. A. F. Gidley, K. Greenwood, J. E. Hardy, E. M. Healey, C. Holden, A. D. Holt, G. D. Hubbard, D. Madoc-Jones, J. H. Mallard, B. E. Moody, K. W. Ogilvie, J. M. Owen, A. T. Partridge, L. G. Penhale, S. Raghavachari, H. M. Rosenberg, D. J. Shapland, E. I. Sherrard, H. J. Stokes, G. W. R. Smith, P. M. Stott, R. Stratton, A. W. S. Tarrant, N. B. Terry, E. B. Whittaker, O. Wilson, H. C. Wright.

Forty-three Graduates, forty-seven Students and six Subscribers were also elected.

Documentation of molecular spectroscopy (D.M.S. system)

The question of documenting and publishing the work of spectroscopists has been much discussed during recent years. A number of systems, all of them using punched cards in one form or another and all of them documenting spectra in the infra-red range, have been published. The publication of a new system of documenting infra-red and Raman spectra is announced jointly by Butterworths Scientific Publications, 88 Kingsway, London, and Verlag Chemie, Weinheim/Bergstrasse, Germany. This new system (D.M.S.) claims several advantages over those hitherto published. It combines a survey of current literature with an expanding collection of spectra of purified substances in classified form. It does not require a sorting machine but yet may be used with one and incorporates a large amount of data on single cards. There are two identical editions, one in English and the other in German.

The D.M.S. system provides two kinds of cards: literature cards provide information in abstract form from papers relevant to molecular spectroscopy, and spectra cards for every substance of which a spectrum of satisfactory quality is available. The spectrum will be reproduced with a linear wave-number scale and the card will also carry the structural formula, physical constants and other data. An important feature of the cards is the coded classification based on the structural units of the molecule which makes unnecessary any separate index.

It is expected to start the D.M.S. Service in 1956 with an initial batch of about 500 cards, and to issue about 2000 cards in the first year of operation. It is also expected that this figure of about 2000 cards annually will be maintained, the proportions being roughly 20% literature cards and spectra cards. The substances to be examined have carefully selected so as to cover a very wide range which satisfy the requirements of both academic and indus users in different applied fields.

Register of British manufacturers

The twenty-eighth edition (1956) of the FBI registe British manufacturers classifies the products and service over 7000 firms who are members of the Federation of Bri Industries. The headings used are: products and serv addresses, trade associations, trade names and trade ma In addition there are language glossaries in French, Ger and Spanish.

The register is published by Kelly's Directories Ltd., Iliffe and Sons Ltd., Dorset House, Stamford Street, Lon S.E.1. The price is 42*s*.

Nuclear reactor data

The Raytheon Manufacturing Company of Waltha Massachusetts, U.S.A., has issued a seventeen-page broc the principal feature of which is a series of charts giving s fifty characteristics of each of the nearly one hundred reac built or under construction in different parts of the wo The compilation was greatly aided by the declassificatio information at the recent Geneva Conference. The reac are classified into the following groups: pressurized wa boiling water; swimming pool; homogeneous; heavy wa graphite; sodium graphite; liquid-metal cooled; liquid fast breeder. Copies of this brochure are available from firm to *bona fide* enquirers, at a nominal charge.

British Journal of Applied Physics

Contents of the February issue

SPECIAL ARTICLE

The United Kingdom Atomic Energy Authority and its functions. By Sir Cockcroft.

ORIGINAL CONTRIBUTIONS

The laminar flow of streams of suspended particles. By T. V. Starkey.
The inductance of two elliptic tubes. By E. E. Jones.
A photographic method of obtaining stress trajectories. By A. R. Morris
A modified replica technique and its application to the examination of e single crystals of barium titanate. By D. S. Campbell and D. J. Stirla
Collodion replicas from cross-sections of thin metallic strip and coatings D. J. Evans.
A comparison of dry stripped, unbacked collodion and Formvar replicas D. J. Evans.
The measurement, by nuclear resonance, of light water concentration in mi of light and heavy water. By A. M. J. Mitchell and G. Phillips.
The thermal and electrical conductivities of deposited carbon. By A. Brown, W. Watt, R. W. Powell and R. P. Tye.
Stress distribution in a tee junction of thick pipes. By H. Fessler and B. H. L

NOTES AND NEWS

Correspondence
Errors in the A.S.T.M. Index of X-ray powder diffraction patterns. From Hughes, Isabel E. Lewis and A. J. C. Wilson.
New books
Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principle construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation* *contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicatio from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Londo E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 6 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addres or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable i advance. Single parts, so far as available, may be purchased at 10*s.* each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

An attachment for high-temperature single-crystal X-ray work

By L. S. Dent, B.A., and H. F. W. Taylor, B.Sc., Ph.D., Department of Chemistry, University of Aberdeen

[*Paper received* 3 *October*, 1955]

This attachment to an X-ray goniometer permits single-crystal or powder photographs to be taken using copper radiation at up to 900° C. A cylindrical heating element of nickel foil is used, and serves also as a β-filter.

umber of high-temperature X-ray cameras for powder k have been described, but little has been reported con-ing cameras for high-temperature single-crystal work. olley(1) described a camera using a cylindrical platinum heating element, but stated that it was not suitable for rate work. Steward(2) used a nickel foil cone as combined er and β-filter for copper radiation at temperatures up to ut 250° C. The present paper describes a similar device eloped during researches on the dehydration of hydrated ates and aluminates, in which a cylindrical nickel foil nent is used. It is an attachment to the Unicam type X-ray goniometer with 6 cm diameter cassette, and is able for single-crystal or powder work with copper ation up to 900° C.

DESCRIPTION

ig. 1 shows the camera with the high-temperature attach-t assembled. The heater unit (Fig. 2) consists of the el foil furnace element *A*, with its nickel supporting leads which are clamped rigidly to a Sindanyo top *C*. This top carries a chromel-alumel thermocouple mounted in twin-silica tubing *D*, reaching almost to the centre of the ace. A plug of asbestos wool *E* closes the top of the ace. Three slides *F*, attached by slotted brass lugs *G*, on vertical rods *H* (Fig. 1) which are carried by a brass np *J*, mounted on the cassette *K*. Lateral adjustment is le using the slotted lugs, rotational by turning the clamp the cassette, and vertical by moving the stops *L* on the s *H*. The power and thermocouple leads are denoted by nd *Y* respectively. The Sindanyo top is placed so that e is an air space between it and the top of the cassette. arries on its underside a circular raised portion which fits sely into the top of the radiation shield described below. ig. 3 gives details of the element. The heater unit is gned so that the two leads *B* lie on either side of the imator, obscuring only a small portion of the film at the n-angle end. To make the element, the foil is cut using emplate *M*; the ends are cut into strips *N* and two 2 mm es *O* are punched. The foil is rolled into a cylinder with ight overlap, using a former. The two nickel rings *P* are ced in position, and the strips, which are cut 5 mm longer n the depth of the rings, are folded over them and held n with cotton thread. The element is placed in its clamps nd oriented so that the X-ray beam will pass through the es. The overlap is placed on the high-angle side. The nps are then tightened and the thread and superfluous removed. This method of mounting allows the foil to and when hot without buckling. Two thicknesses of foil, 20 and 0·025 mm, were tried. The latter is preferable ause it is less likely to burn out at the higher temperatures, ough exposures are slightly longer.

The radiation shield is a cylinder of aluminium foil *R*, 0·012 mm thick mounted on a brass frame (Figs. 1 and 4). It is placed between the heating element and the film, and encloses the goniometer head. In Fig. 4 the foil is partly cut away to show the frame. The supporting strip *S* with the clamping strip *T* is placed in the high-angle position; the collimator passes through the hole *U* and a hole is punched in the foil for the exit of the direct beam. Three locating pegs *V* fit into holes drilled in the camera base.

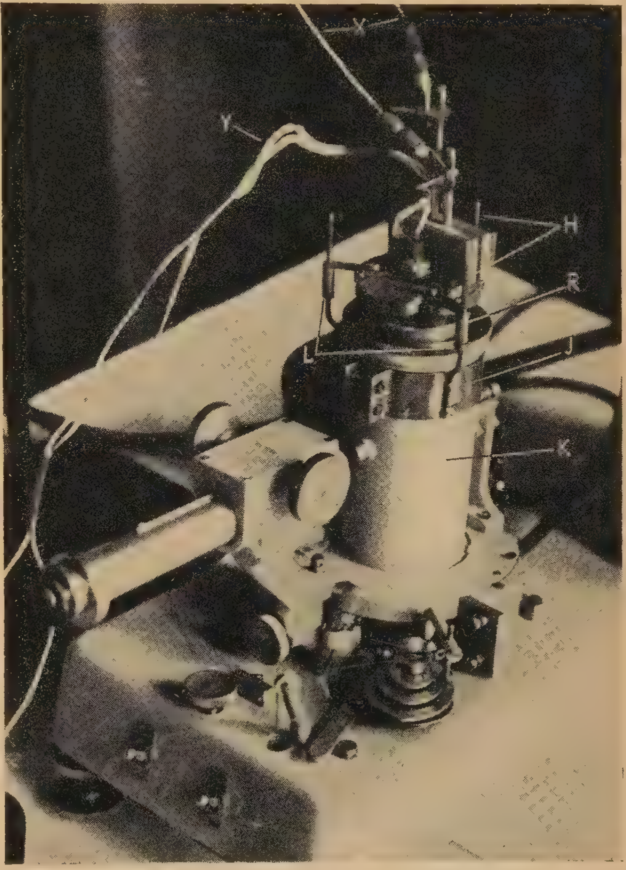


Fig. 1. General view of camera and attachment

The crystal is cemented to a silica fibre about 2 mm long and up to 0·4 mm thick. This is cemented to a platinum wire silver-soldered to the pip which fits on the goniometer head. The wire, 1 mm thick in its lower part, is reduced to half this thickness for the top 3 mm, permitting coarse setting of the crystal by bending the wire. Final adjustment is made using the goniometer arcs, which can be moved about ten degrees from the zero position in any direction without the crystal mount fouling the furnace. To keep the goniometer head away from the furnace, a new collar 4 mm shorter than the original was made for it, and the length of the shaft on which it is mounted was reduced by 9·5 mm.

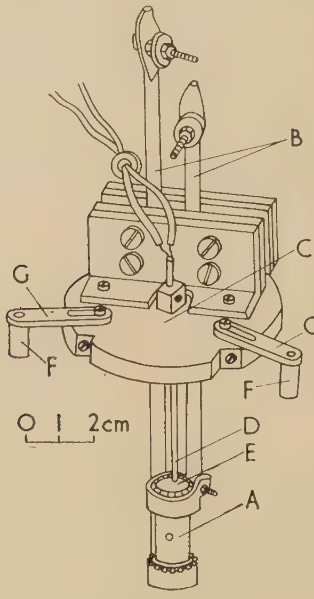


Fig. 2. Heater unit

For the study of transitions above 200° C, waterglass is a suitable cement. It swells at 150–200° C, and must be heated to 200° C before final setting of the crystal. For work at lower temperatures, Seccotine or other organic adhesive is more satisfactory. These carbonize but can usually be relied on up to 300° C.

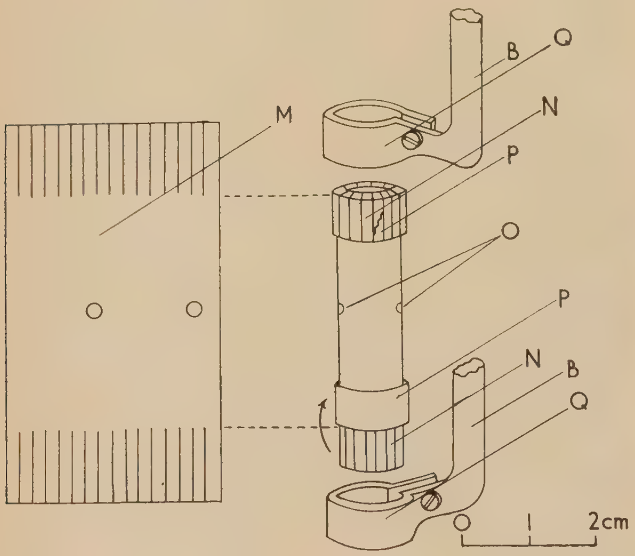


Fig. 3. Details of element and clamping arrangement, shown partly exploded, with template on left

Power is supplied by a transformer giving up to 60 A at 4 V, fed through a Variac preceded by a constant voltage transformer. The element runs at about 10 W at 2
30 W at 500° C, and 100 W at 900° C.

The thermocouple junction is about 1 mm abov
crystal, just clear of the X-ray beam. For calibration, cr
of various substances were mounted, and their melting p
observed using the telescope and collimator light.
difference between true melting point and temper

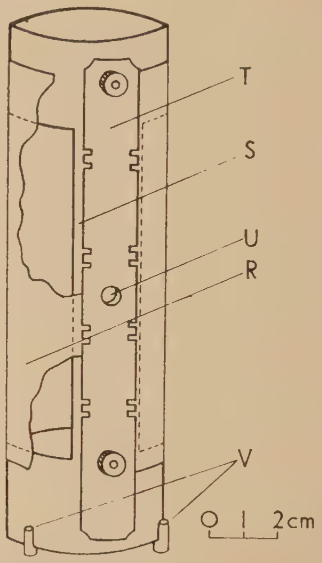


Fig. 4. Radiation shield

recorded by the thermocouple was only a few degrees,
was ignored. A temperature stable to within two or
degrees is reached in about fifteen minutes.

PERFORMANCE

The principal use of the attachment is the study of th
transitions in which orientation is preserved, especially w
the transformation is rapidly reversed on cooling.
$\alpha-\beta$ quartz transition at 573° C affords an example. F

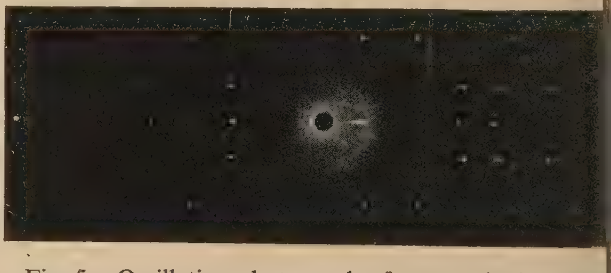


Fig. 5. Oscillation photograph of quartz single crysta
$1\frac{1}{2}$ h at room temperature followed by $1\frac{1}{2}$ h at 710°
Copper radiation; 15 degree oscillation about *C*

is an oscillation photograph of quartz in which the speci
was maintained first at room temperature and then at 71
with the same film in the camera. The doubling of mo
the reflexions is caused by the conversion into the h
temperature β-form, which gives reflexions with hi
d-spacings. By experiments of this kind the orientation
high-temperature product relative to that of the star
material can be found.

: furnace temperatures above about 500° C it is advisable low cold air on to the outside of the cassette to prevent id the film from becoming warm. This was found more tive than blowing air into the space between the radiation d and the film, and also did not cause the furnace erature to fluctuate.

ickel has a fairly low mass absorption coefficient for bdenum radiation, and the nickel heating element could ably be used with it, although it would not act as a ter. Experiments have indicated that it may be possible se zirconium in place of nickel foil; this would give a filter furnace more suitable for use with molybdenum radiation.

ACKNOWLEDGEMENT

We thank Mr. A. Barclay for much help in the design and construction of the attachment.

REFERENCES

(1) Woolley, R. L. *J. Sci. Instrum.*, **25**, p. 321 (1948).
(2) Steward, E. G. *J. Sci. Instrum.*, **26**, p. 371 (1949).

An ultrasonic apparatus for recording the height of water waves in model ship tanks

By E. G. Richardson, D.Sc., F.Inst.P., King's College, University of Durham, Newcastle upon Tyne

[*Paper first received* 17 *October, and in final form* 28 *December*, 1955]

An apparatus is described for measuring the height of water waves on the surface of a model ship towing or manœuvring tank. The apparatus uses an ultrasonic transducer on the bed. This pulses toward the surface and the echoes returned from successive crests and troughs are recorded continuously on an oscillograph.

detection of obstacles in water and of crevices in solids he echo therefrom of an ultrasonic train is a well-known ciple. The apparatus to be described arose out of a irement to measure the height of the waves formed on surface of water such as are set up in tanks in which model s are towed or manœuvred. The established method of ıg this, apart from observing the simple rise and fall of water on a stick, is to record the variations in electric citance between an electrode and the free surface (which lves possible obstruction of model surface craft and narines). A device in which the only apparatus put into tank is set on the bottom has some advantages. Such, example, is the pressure-recorder devised by the author* neasurements on the sea-bed itself, from which the waveht may be calculated. It is, however, rather cumbersome the present purpose. Instead an ultrasonic transducer ed on the floor of the tank sends pulses to the surface, h are reflected by troughs and crests alternately, whence return as echoes to the transducer and are recorded on scillograph.

APPARATUS

barium titanate transducer of 3 Mc/s is laid underwater upward. A conventional circuit consisting of a keyed lator applies pulses at a repetition rate of about 200 per nd to the transducer so that it repeatedly "pings" a of ultrasonic waves towards the surface and receives the es back before the next outgoing pulse. (The pulse hs used range from 10 to 20 μs.) The echoes, diminishn intensity with path length, are due to successive passages e sound between source and surface. They and the nal pulse are passed through a tuned amplifier to an loscope, on the screen of which they are exhibited while weep is in operation, synchronized to the repetition rate. ting, say, the first or second echo, its rhythmic moves are observed as the height of water above the transr varies with the passage overhead of successive crests troughs. It is, in fact, usually only the extremes of motion of the water which are observed, the sloping portions of the waves when overhead sending echoes which miss the transducer. Thus in the normal way of exhibiting the echoes, as vertical shifts of the electron spot while it is swept horizontally, the spot first jumps up as a trough passes over, dies out and re-appears further along the swept trace as the crest passes over. The shift is an absolute one, i.e. it is independent of water depth.

The echo from the crest is more intense, i.e. the signal on the screen is larger than that from the trough and the latter is more spread out. This is due to the fact that the former signal comes from a slightly concave and the second from a slightly convex mirror surface [Fig. 1, (*a*) (*b*)]. When the outgoing pulse strikes an inclined portion of the wave [Fig. 1(*c*)] the reflected pulse fails to strike the transducer.

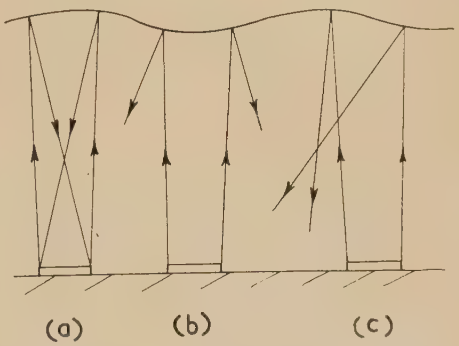


Fig. 1. Transducer on floor of tank sending pulse towards water surface in three different positions relative to wave configuration

The distance across the oscilloscope screen between these two signals has then to be measured in terms of the corresponding vertical distance between crest and trough. This is done by fitting a "calibration pot" over the transducer. It consists of a brass cylinder about 1 ft long open to the water below and supported on three feet with levelling screws. Inside the pot a reflecting piston can be moved up and down in the water on a screw. The procedure of calibration then is to move the piston by a known amount to replace the vertical motion in a wave, and observe the resulting shift of the echo on the screen.

---

* Richardson, E. G. *Phil. Mag.*, 37, p. 25 (1946).

TESTS OF WAVE-HEIGHT RECORDER

The apparatus has been used in the wave-making ship tank (depth 30 in. wave heights up to 4 in.) and has worked satisfactorily at the Admiralty Experiment Works.

For continuous recording, the signal display described above is inconvenient to photograph, but spot-brightness modulation is possible on most oscillographs, whereby the spot is still swept from left to right but only shines where the original pulse or the echoes come in. Thus under the waves each echo appears as a spot which shines out first in one position, then, later, a little further to the right. (The film in the camera, must, of course, move in a vertical direction.) This technique has been successfully applied to record continuously wave heights on this apparatus (Fig. 2).

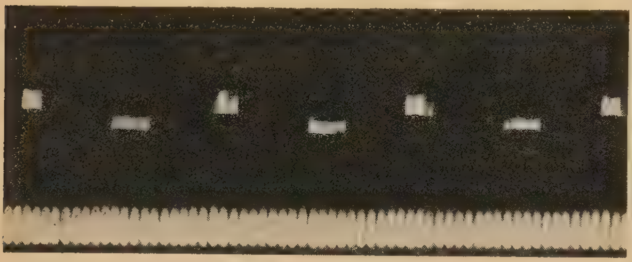


Fig. 2. Typical oscillograph record under water; below, mark of initial pulses; above reflexions from successive crests and troughs

As far as the particular application is concerned, there is an optimum frequency just as in Asdic techniques. The "spread" of the diffracted energy emitted by the transducer is represented by a solid angle, the projection of which i plane has a sine $0\cdot6\,\lambda/R$, where λ is the ultrasonic wave in water and R is the radius of the transducer. This ind that the transducer disk should be made as wide as po and the frequency as high as possible; in the present app $R = 12\cdot5$ mm and $\lambda = 1\cdot5$ mm so that the beam c circle of 15 mm radius at the surface of the water above the bed, larger circles being cast at proportio greater depths. This factor also affects the "resolving p in the sense that the device will not properly detect a s wave, the successive crests and troughs of which between them a shorter distance than twice the sine c angle, for then the reflexions from one crest and the trough will arrive simultaneously at the transducer and the sharpness of signal.

Although these considerations would indicate tha should use the highest possible frequency, there will limit in great depths, due to the molecular absorption i water which increases roughly as the square of the frequ

When trying to assess the advantages and disadvanta the ultrasonic recorder over other devices, e.g. the cap probe, one notes two main points. The ultrasonic rec involves no impediment to the model which is impor a "manœuvring tank" where the model may be foun occasion at almost any point on the free surface. It i so sensitive as the capacity probe but, in the author's ex ence, requires less setting up and testing, the elect being simpler. The transducer is a small object which be dropped like a coin or moved about quickly from to place on the bottom of the tank. On the other han the reasons given, it cannot record the complete shape o wave, only the "flats" thereof.

ACKNOWLEDGEMENT

The design and test of this apparatus was carried ou the author at the Admiralty Experiment Works, Han the Superintendent of which, and to his Staff, he expr his appreciation of facilities and assistance afforded.

Devices for automatic potentiometric titration

By R. Audran, Kodak-Pathé S.A., Vincennes, France, and D. T. R. Dighton, M.Sc., A.Inst.P., Kodak Ltd., Harrow, Middlesex

[*Paper received* 17 *October*, 1955]

Two devices capable of automatically performing titrations are described. Both control an electromagnetically operated burette tap from the output of a suitable electrode. The first device, which uses an electronic valve amplifier, is adaptable to any titration the end point of which can be determined potentiometrically. The second, which makes use of a sensitive relay, is only suitable where the electrode used has a low internal resistance.

Where a large number of routine potentiometric titrations have to be carried out, time and skilled labour can be conserved by the use of a burette tap controlled electromagnetically from the electrode output. The basis of the method is the continuous comparison of the electrode potential with the equivalence potential, the difference between them being made to operate the burette tap either directly, *via* relays, or after amplification; the circuit is arranged so that the tap closes when this difference falls to zero.

This principle has been applied to the determination of the silver content of photographic emulsions. The analy method used is the well-known one involving the addi of excess potassium cyanide, followed by back titratio the equivalence point with silver nitrate solution. The point can be shown by the appearance of turbidity but back titration is more usually performed using the silver electrode/silver ion solution/calomel electrode, output of which is measured with a potentiometer. automatic method described in this paper is applicabl any titration which can be performed potentiometrica Experience with the equipment is, however, confined to ne determination of silver under conditions mentioned w. For this work, both pieces of apparatus have proved factory.

PRINCIPLE OF OPERATION

ne curve showing the variation of potential of a silver rode with the volume of silver nitrate added is of the shown in Fig. 1. The equivalence potential is about nV for the cell: silver electrode/silver ion solution/calomel rode. As soon as the electrode is immersed in the tion the electrically controlled burette tap is fully opened, r nitrate runs into the solution and the electrode output

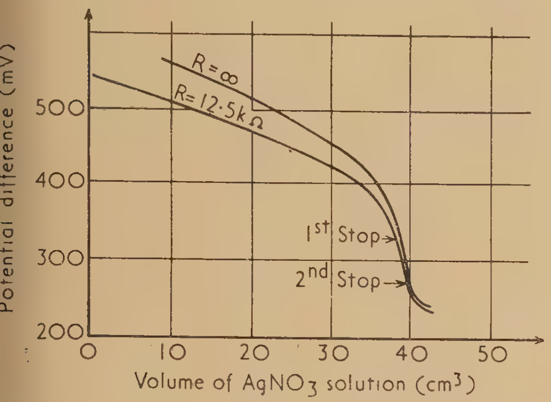


Fig. 1. Electrode output as a function of volume of solution added and electrode circuit resistance, 1 cm^3 AgNO$_3$ solution ≡ 1 mg Ag

When the electrode potential reaches about 100 mV n the equivalence potential, the tap partially closes giving ow rate of flow (1 drop in 5s) until equivalence is reached; his point the tap is fully closed.

CTRONIC DEVICE FOR AUTOMATIC POTENTIOMETRIC TITRATION

escription of circuit. The circuit diagram of the electronic ipment is shown in Fig. 2. The potential from the trode is interrupted at 50 c/s by a Carpenter relay operated n the valve heater supply. The direct use of this relay is sible since the electrode used has an internal impedance bout 2 000 Ω.

he d.c. potential from the electrode is compared at the of the first valve with a variable potential derived from voltage reference tube V_4. This enables the electrode ential to be "backed-off" and the device set to close the when the equivalence potential is reached. The potentioer R_{13} which controls this critical potential is fitted with a calibrated in millivolts.

he output from the Carpenter relay is of square wave- n and of peak-to-peak amplitude equal to the d.c. erence between the electrode potential and the equivalence ential, and is amplified by the double triode V_1. The out from V_1 is rectified by V_2 and applied as a negative to the triode V_3 which has in its anode circuit the relays trolling the electromagnetic tap. Thus the change of de current of V_3 is proportional to the change of electrode ential. The circuit is arranged so that V_3 carries about A when there is no input to this valve.

n operation the "backing-off" potential is set to the equivalence point. When the electrode is immersed in the solution the output takes up a value dependent upon the excess cyanide present (usually about 550 mV). Thus a 300 mV signal is applied to the grid of V_{1a}. This is sufficient to bias V_3 to cut-off, and both relays in the anode circuit are de-energized: the contacts on these relays are so connected that the tap is then fully open. As the titration proceeds, N/20 silver nitrate solution is added and the input signal to the amplifier falls; when it reaches 130 mV the anode current of V_3 has risen to about 1 mA and relay *A* operates, reducing the current flowing in the tap solenoid and reducing the rate of flow from the burette tap to 1 drop in 5s. The electrode potential difference continues to fall until the input signal is 30 mV, when relay *B* operates and closes the tap, terminating the titration. This occurs when the anode current of V_3 is about 6·5 mA. It may be helpful to present these changes in the diagrammatic form shown in Fig. 3. In the neighbourhood of the equivalence point, one drop of N/20 silver nitrate solution added to a total of 150 cm^3 of solution produces a change of potential of 30 mV.

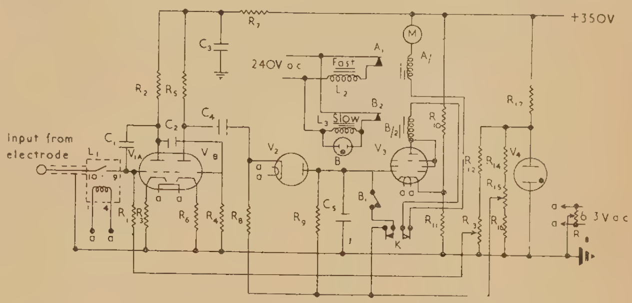


Fig. 2. Circuit of automatic titration device (all contacts shown in "titration completed" state)

$R_1 = 1$ MΩ
$R_2 = 220$ kΩ
$R_3 = 3{\cdot}3$ kΩ
$R_4 = 1$ MΩ
$R_5 = 220$ kΩ
$R_6 = 3{\cdot}3$ kΩ
$R_7 = 100$ kΩ
$R_8 = 1$ MΩ
$R_9 = 2{\cdot}2$ MΩ
$R_{10} = 55$ kΩ
$R_{11} = 3{\cdot}3$ kΩ
$R_{12} = 81$ kΩ
$R_{13} = 1$ kΩ
$R_{14} = 74$ kΩ
$R_{15} = 5$kΩ
$R_{16} = 51$ kΩ
$R_{17} = 36$ kΩ
$R_{18} = 250$ Ω

$C_1 = 50$ pF, 500 V
$C_2 = 0{\cdot}05$ μF, 500 V
$C_3 = 8$ μF, 500 V
$C_4 = 0{\cdot}05$ μF, 500 V
$C_5 = 0{\cdot}1$ μF, 500 V

V_1 = 6SL7
V_2 = Mullard EA50
V_3 = 6V6
V_4 = Mullard 85A2

K = key switch

B = ½ W neon lamp

L_1 = Carpenter relay, Type 5C6
L_2, L_3 = solenoids, Webber Type SA

A/1 = P.O. type 3 000 relay, 10 kΩ

B/2 = P.O. type 3 000 relay, 1 kΩ

M = milliammeter 0–10 mA

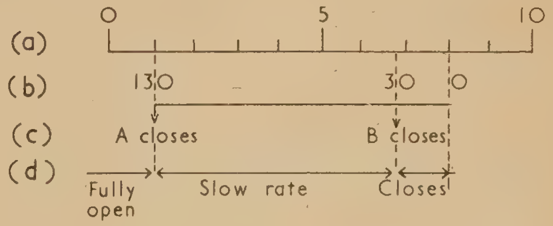


Fig. 3. Illustration of burette tap operation

(*a*) V_3 anode current (mA); (*b*) mV input to amplifier (peak to peak); (*c*) relay operation; (*d*) tap operation.

With this system, it is necessary for the anode current of V_3 to remain constant, independent of supply voltage changes, when there is no amplifier input. This arises from the necessity of maintaining a constant difference between the current at which relay *B* operates and the no-signal current. The effect of supply voltage on V_3 has been greatly reduced by connecting this valve as a mu stabilizer. Thus, the control grid of V_3 is kept at a constant positive potential by means of the voltage reference tube V_4. A proportion of any change of high tension voltage is applied to the cathode of the valve by means of a potential divider and it can be seen that this will tend to produce a change of anode current of opposite sense to that due to the direct change of high tension voltage. It can be shown that if the ratio of the potentiometer supplying the cathode is nearly equal to the amplification factor of the valve the anode current is independent of high tension voltage. With this circuit the anode current is held constant to 1% for changes of mains supply voltage of 20%.

The meter scale has a narrow green band between 7·75 and 8·25 mA and the needle should fall within this band in the waiting condition. A pre-set potentiometer R_{15} available at the rear of the instrument is used to compensate for valve aging.

Detailed operation of relay circuit. At the start of a titration the relay contacts are in the positions opposite to those shown in Fig. 2 and the solenoids L_2 and L_3 are de-energized, fully opening the tap. When relay *A* operates, the slow rate of flow is obtained. At the end of the titration, all relays and solenoids are energized, and the lamp *B* lights. The contact B_1 then shorts out the signal so that the tap will not be opened again until the operator is ready to start another titration.

To facilitate setting up the equipment, a key switch *K* is fitted. Before a titration is begun, the liquid level in the burette may be adjusted by moving this key switch to the right of the central position. This breaks the anode circuit of V_3 and the tap is opened. When the key is moved to the left the signal is applied to the control grid of V_3, biasing this valve to cut-off and opening contact B_1; the titration then proceeds. The left-hand movement of *K* has a spring return action and it is therefore only necessary to push it momentarily to the left to open the tap.

Description of tap. Diagrams of the electrically-operated tap are shown in Fig. 4. It employs a branched glass tube to the arms of which are attached two jets by means of thin-walled plastic tubing. The liquid flow is interrupted by compressing the tubing by a roller mounted on a lever and trolled by a solenoid. The two rates of flow are obtain using two jets of different size. The jets and plastic are of small internal diameter to minimize the risk of dra in an irregular volume of air when the tap closes.

The action of the roller is to force the tubing agai Perspex bridge: this bridge also holds the glass and p tubing in place on the front of the box containing the solenoids. The bridge is removable to permit cleaning replacement of the tubes. The roller compresses the tu through a thin impermeable membrane; this seals mechanical and electrical components from the corr action of reagents.

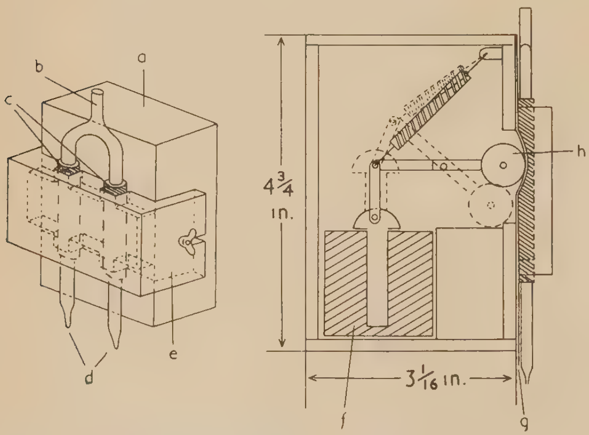


Fig. 4. Compression type electrically controlled burette tap

a, Perspex box containing solenoids; *b*, glass T-piece; *c*, polyvinyl chloride tubing, outer diameter, 4 mm; inner diameter, 2 mm; *d*, slow and fast glass capillary jets; *e*, Perspex bridge; *f*, Webber solenoid type S.A.; *g*, impervious flexible sheet; *h*, clear Perspex

The liquid flow must be uniform and independent o height of the liquid in the burette; this is important in that equilibrium is always reached under similar conditi It has been found desirable to replace the ordinary si burette by the model represented in Fig. 5; it is based o principle of the Mariotte vessel. The small upper valv rendered air tight by being wetted just before titration du the filling up operation. The rate of flow is controlle the constant pressure given by the distance (*h*) between end of the capillary and the end of the tap.

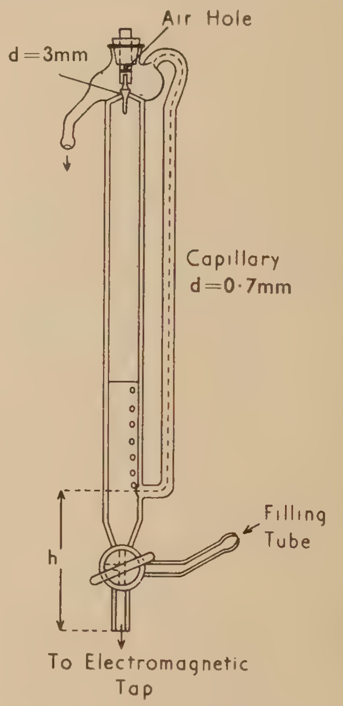


Fig. 5. Constant head burette

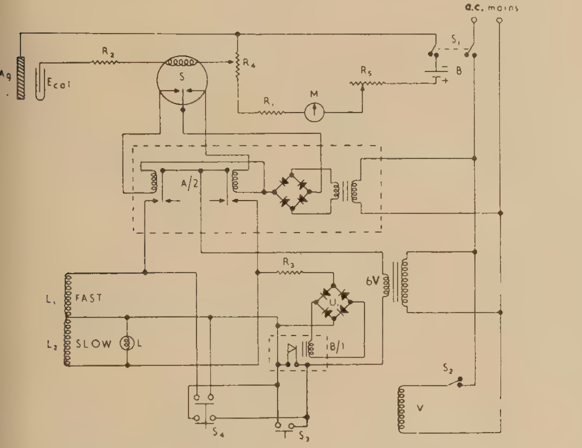
Standardization. Before a series of titrations is begun, necessary to standardize the equipment so that the closes at the equivalence point. This may be done by carr out a titration by normal means and, with the electrod the solution at the end point, setting the backing-off con so that the tap relays just operate.

SIMPLIFIED DEVICE USING SENSITIVE RELA

Another form of automatic titration device, which does make use of electronic valves, has been made possible by availability of very sensitive moving coil relays. The princ of operation is the same as for the apparatus described ab ne current taken from the electrode system in this method ppreciable. It is found, however, that it does not alter position of the point of inflexion of the curve of potential function of volume of silver nitrate added; this can be from Fig. 1. This constancy of the equivalence potential e result of using a reference electrode of large area (20 cm^2 ee mercury surface) which is virtually free from polariza- effects. The silver electrode does not seem to become rized under these operating conditions.

he moving coil relay which is of the Sensitact type manu- ured by Ste. Brion-Leroux, Paris, is operated direct from electrode system and has a set of changeover contacts h control the burette by means of an auxiliary relay and her form of tap described below.

escription of the apparatus. The resistance of the electrode uit is about 12 500 Ω of which 7 500 Ω is the internal tance of the moving coil relay. This relay has a minimum rating current of 0·4 μA equivalent to 3 mV applied ss the coil. These values apply for a Sensitact relay S, reference 911.289. One of the contacts is set to close) mV, the other at 0 mV. The backing-off potentiometer in Fig. 6 is standardized using the rheostat R_5 and a



ig. 6. Circuit of titration device using sensitive relay

R_1 = 2 kΩ
R_2 = 4·5 kΩ
R_3 = 100 Ω

S = Sensitact relay 7·5 kΩ
$A/2$ = secondary relay supplied with S
$B/1$ = P.O. type 3 000 relay 200 Ω
B = 1·5 V dry cell
U_1 = bridge rectifier 10 V 20 mA

R_4 = 1 kΩ
R_5 = 1 kΩ

M = milliammeter 0–1 mA
L = indicator lamp 6 V 0·3 A
L_1, L_2 = tap coils
V = stirrer

oration mark on the milliammeter. The potentiometer raduated from 100 to 350 mV. The secondary relay unit is supplied with the Sensitact relay; it consists of two vidual relays each with changeover contacts. The ing relay $B/1$ (6 V, 8 mA) is intended to ensure that the is not re-opened after the end point is reached. After ration is completed, the relay can be re-set for the next by operating the push-button S_3. Another push-button ermits manual operation of the tap as required.

he method of operation is as follows: with the beaker aining about 20 cm^3 of solution, the main switch S_1 is ed and the needle of the milliammeter adjusted by means he rheostat R_5. The potentiometer R_4 is set to the ivalence potential (or 5 mV below it) as determined viously for the conditions of the titration. When S_3 is sed, the burette tap opens on the full rate of flow until first contact of the relays closes (at 70 mV from the equivalence potential). The slow rate of flow—1 drop in 5s—is then obtained and this continues until the second contact of S is made, when the tap is closed and the titration completed. A solution of silver nitrate containing 1 mg silver/cm^3 is convenient for use with this apparatus.

Alternative tap design. This simplified apparatus has been used in conjunction with a different tap to the one described earlier: the second unit is shown in Fig. 7. It consists of a glass tube with a jet at the lower end and a central chamber containing a glass-sealed soft iron armature. When this armature is at its lowest point the two ground surfaces are in contact and no liquid passes through. At the highest point the small glass stopper is lifted from its seating and a full flow of liquid (0·25 cm^3/s) occurs. In an intermediate position of the armature this stopper, which is ground-in but provided with a small flat, permits a drop of liquid to pass through the tap every few seconds. The position of the armature is controlled by two coils round the tube, these being energized through the relays from a 6 V, 50 c/s, a.c. supply. The coils consist of 500 turns each of 32 s.w.g. enamelled copper wire wound on a Tufnol bobbin. When this tap is used it is necessary to filter the solution carefully.

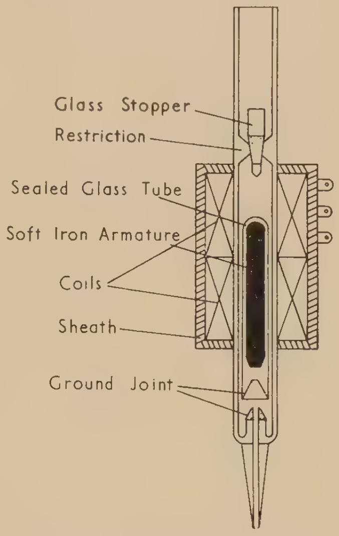


Fig. 7. Plunger type electrically controlled burette tap

There is, of course, no reason why the other design of tap should not be used with this equipment, provided the circuit is modified accordingly.

ACCURACY OF THE APPARATUS

With apparatus of this sort the accuracy of titration is almost completely dependent upon the speed of response of the electrode and the rate of reaction of the electrolyte. In practice the electrolyte and the electrode reach equilibrium in about 4 s. Thus, with a slow rate of flow of 1 drop in 5 s, the possibility of overshooting is small.

The precision of the electrical equipment corresponds, near the equivalence point, to one drop of the silver nitrate solution. There is also an uncertainty of one drop in the volume of liquid added, making a total uncertainty of 0·1 cm^3. Over a series of five titrations the electronic apparatus has given a range of 6 mV between extreme values of end point potentials. This error must, of course, be added to the others inherent in the method: accuracy of reading, solubility of the precipitate, accuracy of making-up solutions, etc.

Some notes on the design and performance of X-ray proportio counters

By A. R. Lang, M.Sc., Ph.D., A.Inst.P.,* Cavendish Laboratory, University of Cambridge

[*Paper received* 13 *September*, 1955]

For proportional counting of X-ray wavelengths used in diffraction, xenon is the best counter gas, krypton the least suitable. A small, high-efficiency, low-background, xenon-filled counter is described. Argon and xenon counters containing about 10% ethylene operate stably with 50 000-fold multiplication of CuKα ionization, but for undistorted pulse-height distributions at counting rates greater than 10 000 per second multiplication should not be greater than a few thousand. Diffraction pattern background intensity of light elements, such as aluminium, is reduced to ½ to ⅔ of the value as registered by a Geiger counter.

1. INTRODUCTION

The successful use of the proportional counter in X-ray diffraction work was reported in 1951,$^{(1)}$ and these counters are now commercially available as alternatives to Geiger counters in standard diffraction equipment. The following notes are offered to supply some guidance to those who may wish to build their own counters, and also to provide some background information for users of commercial equipment. They are drawn largely from a detailed study of the X-ray applications of proportional counters undertaken by the author.$^{(2)}$ A general discussion of the proportional counter and its application to X-ray diffraction is included in a recent article by Arndt$^{(3)}$ which lists publications on this subject. The properties of the proportional counter as an energy-measuring device have been reviewed by West.$^{(4)}$ The considerable advantages in X-ray work which these counters offer over Geiger counters may be summarized as follows. Proportional counters of the design used by the author (i) have negligible dead-time, (ii) have a low natural background, (iii) can be used to discriminate against unwanted radiations, (iv) are more efficient than standard Geiger counters, and (v) do not give spurious or multiple counts, hence the counting rate does not vary independently of the source intensity.

2. X-RAY PHOTON ABSORPTION PROCESSES

The essential conditions to be satisfied in the design of an X-ray proportional counter are that all, or a well-defined fraction, of the energy of the incident X-ray photon be converted into ionization in the counter gas, and that all electrons produced in this absorption process be subject to the same multiplication. In order to be competitive with the Geiger counter, the proportional counter should possess no less efficiency. Constancy of multiplication demands accurate construction of the counter body and, a very stringent condition, freedom from negative-ion formation. A criterion of adequate efficiency is that in the case of CuKα radiation, say, the product of counter gas atomic absorption coefficient, gas pressure and effective path length of the X-rays in the counter be such as to give an absorption efficiency not less than 60%. The desirability of obtaining a low natural background, together with considerations of mechanical convenience, emphasize the advantages of compactly designed counters. The gas filling can be at or near atmospheric pressure, but with thin-window counters it is not desirable to go much above this pressure.

In Figs. 1(*a*) and (*b*) the variation with X-ray wavelength of the absorption efficiency of certain noble gases is plotted

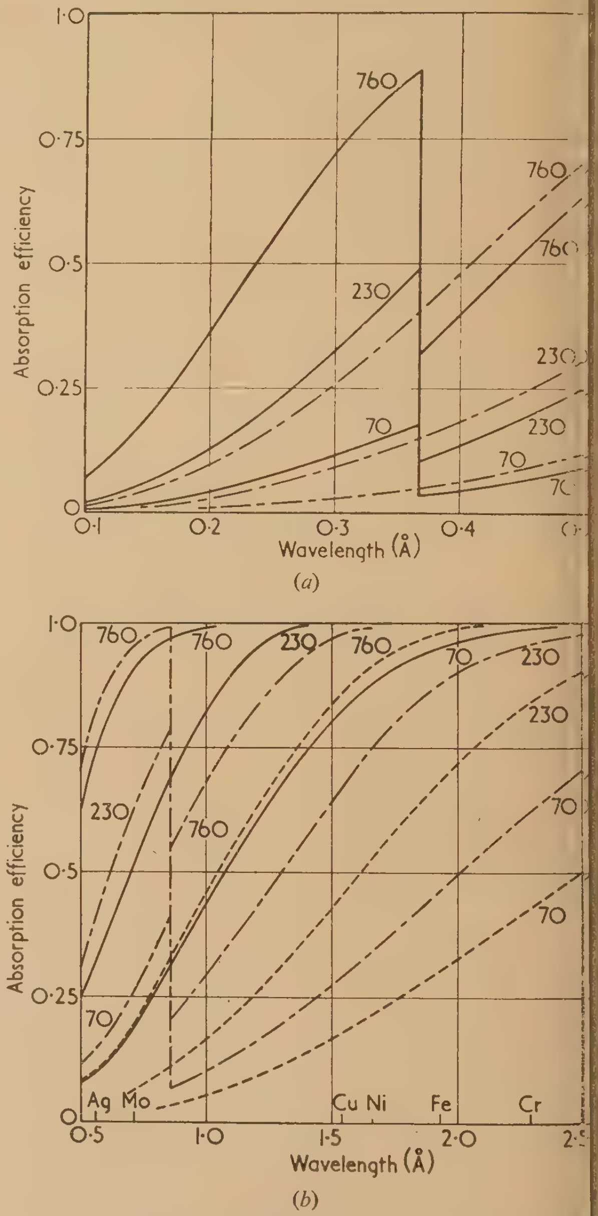


Fig. 1. Absorption efficiencies of noble gases, xeno krypton and argon, with absorbing path (*l* cm) × pressu (*p* cm of mercury) = 760, 230, 70; (*a*) $\lambda = 0{\cdot}1 - 0{\cdot}5$ (*b*) $\lambda = 0{\cdot}5 - 2{\cdot}5$ Å

——— = xenon; — — — = krypton; - - - - = arg three typical values of the product of pressure (p, in cm mercury) and active length (l, in cm). The product = 760 would correspond to an end-window counter of . active length at atmospheric pressure, $lp = 230$ to a n. diameter, side-window counter at atmospheric pressure, $lp = 70$ to a ¾ in. diameter, side-window counter filled a pressure of 35 cm of mercury. Fig. 1(*b*) covers the ge of characteristic radiations normally used in diffraction k, AgKα to CrKα, whereas Fig. 1(*a*) extends down to Kα wavelengths of the heavy elements which may be ountered in fluorescence analysis. In this region a ntillation counter would normally be used, but in some cumstances, noted below, the proportional counter may be ferred on account of its higher discriminating ability. The h efficiency of xenon is noteworthy, but a high efficiency the particular characteristic wavelength to be measured is the only desideratum, for preferably it should be com- ed with a low efficiency for other wavelengths necessarily duced by the X-ray tube. In the range CuKα to CrKα on is the best in this respect, but xenon is little inferior, ce if the peak kilovoltage is not above 40 to 45 the amount white radiation emitted shorter than the K absorption edge xenon (34·6 kV) is small. Krypton is seen to be quite uitable except in the wavelength region between its K orption edge (0·86 Å) and that of xenon (0·36 Å), and n in this range other characteristics, pointed out below, ke it undesirable for use as a proportional counter filling. e linear absorption coefficients (μ) and half-value thick- ses ($L_{\frac{1}{2}}$) at normal temperature and pressure of argon, pton and xenon are listed in Table 1 for CuKα and MoKα iations.

---

* Now at Harvard University, Massachusetts, U.S.A.

Table 1. *Absorption of CuKα and MoKα in A, Kr, Xe*

	MoKα		*CuKα*	
as	μ (cm⁻¹)	$L_{\frac{1}{2}}$(cm)	μ (cm⁻¹)	$L_{\frac{1}{2}}$(cm)
	0·0224	31	0·201	3·45
r	0·326	2·1	0·370	1·87
e	0·242	2·9	1·94	0·36

Vhen an atom is ionized in an inner shell, say the K shell, a high energy photon, filling of the vacancy by an outer tron may either be accompanied by the emission of characteristic radiation or the excess energy may be com- nicated to another electron, in the same atom, which is n ejected. In the heavier atoms this reorganization will ceed in several steps, and a number of low energy Auger trons can be ejected in turn. A CuKα photon, of energy 4 keV, has the greatest probability of being absorbed in K shell of argon. The K absorption edge energy is 1 keV, so a photoelectron is emitted with energy 8·04 — 3·21 = 4·83 keV. Following this, either argon K radiation (energy of Kα = 2·96 keV) or an Auger electron of short range is emitted. The absorption of argon K radiation in argon is more efficient than that of CuKα radiation, but some of the fluorescent radiation will be lost in the counter walls. The fraction of radiation escaping may be reduced by increasing the counter pressure and dimensions, but it can be seen that however efficient absorption is, the probability of loss in the counter walls is approximately 50% for fluorescent radiation produced very near the entry or exit points of the primary X-ray beam. The probability of K-radiation emission, the fluorescence yield ω_K, is low in the case of argon, about 0·1, so fortunately only a small fraction of pulses will appear in the "escape peak" at an energy of 8·04 − 2·96 = 5·08 keV. Clearly it is very desirable that counter pulses should be concentrated in one energy peak when pulse discrimination is attempted. Hence, if possible, a counter gas should be chosen with a low value of fluorescence yield of radiation excited by the primary X-rays. Table 2 shows the wavelengths, energies and penetrating powers at normal temperature and pressure of the most important fluorescent radiations excited in argon, krypton and xenon. The internal conversion coefficient (I.C.C.) is the complement of the fluorescence yield ω; the values have been selected from measurements by the proportional counter method in the case of ω_K and by the cloud chamber method in the case of ω_L. In both these methods allowance must be made for ionization produced by absorption of the incident photon in shells other than that being studied: this correction involves the relevant absorption edge jump J, which in the case of J_L is not known at all accurately.(5) It is easily shown that

$$\omega = \left(\frac{E}{M+E}\right)\left(\frac{J-1}{J}\right) \qquad (1)$$

where M and E are respectively the numbers of proportional counter pulses in the main peak and in the absorption-corrected escape peak, and that in the cloud chamber

$$\omega = \left(\frac{P}{P+A}\right)\left(\frac{J}{J-1}\right) - \frac{1}{J-1} \qquad (2)$$

where P is the total number of primary photoelectron tracks, and A is the number of these accompanied by tracks of Auger electrons produced by internal conversion of the primary fluorescent radiation. It is incorrectly stated by Burhop(6) that equation (2) may be applied to proportional counter measurements of ω, upon identifying E with P, and M with A. Differentiation of equations (1) and (2) shows that ω-values obtained by the proportional counter method are less sensitive to uncertainty in J than those found by cloud chamber provided that $\omega < 0{\cdot}5$, and *vice versa*.

Table 2. *Ranges and energies of fluorescent X-rays*

		Absorption edge			*Fluorescent X-ray*					
Gas	*Atomic number Z*	*Shell*	*λ (Å)*	*Energy (keV)*	*Line*	*λ (Å)*	*Energy (keV)*	*μ (cm⁻¹) N.T.P.*	*$L_{1/2}$ (cm) N.T.P.*	*I.C.C.*
A	18	K	3·87	3·21	Kα	4·19	2·96	0·32	2·17	0·89(7)
Kr	36	L III	7·38*	1·68	$L\alpha_1$	7·83*	1·58	19·5	0·03	0·92(9)
		L II	7·17*	1·73	$L\beta_1$	7·58*	1·64			
		K	0·865	14·3	Kα	0·98	12·6	0·86	0·81	0·33(8)
Xe	54	L III	2·59	4·79	$L\alpha_1$	3·01*	4·1	10·9	0·06	0·79(9)
		L II	2·42	5·08	$L\beta_1$	2·80*	4·4			

* Interpolated values.

In accordance with prediction, argon-filled counters, and xenon-filled counters used to detect radiations with $\lambda > 0{\cdot}36$ Å, show satisfactorily small escape peaks. Apparent ratios E/M are respectively 1/25 and 1/33 for typical argon and xenon X-ray counters. On the other hand, with a krypton counter used in the wavelength region below 0·86 Å, i.e. in just that region where krypton shows advantageous absorption characteristics, about half the pulses will appear in the escape peak. Even if the latter are sacrificed during pulse-height discrimination and only the main peak pulses are counted, the quality of diffractometer records will be impaired by the superimposition upon the characteristic radiation main peak of the escape peak of white radiation with energy 12·6 keV greater than the characteristic radiation used. Also, in the case of MoKα radiation (17·4 keV), the escape peak of harmonic radiation ($34{\cdot}8 - 12{\cdot}6 = 22{\cdot}2$ keV) will slightly overlap the main MoKα peak.

The relatively high probability of loss of KrKα and XeKα from krypton- and xenon-filled counters can be turned to advantage in the proportional counter method of X-ray spectroscopic analysis. A higher energy-resolution of primary radiation can be obtained by analysis of the pulse-height distribution of the escape peak rather than of the main peak; this is shown as follows. Let W be the width at half-height of the distribution of pulses of mean energy E (both W and E being measured in keV). Now $W = aE^{\frac{1}{2}}$, and the constant a is found experimentally to be about 0·35. If E is the energy of K characteristic radiation of an element of atomic number Z contained in the specimen being analysed, $E^{\frac{1}{2}} \propto (Z - 1)$, by Moseley's law. For $Z \gg 1$ this may be written $E = bZ^2$, approximately, and the constant b is about 0·01. The increment in E, ΔE, when Z increases by unity is $2bZ$. A measure of the resolving power of the proportional counter is the ratio $\Delta E/W$, and, from above, $\Delta E/W = 2bZ/ab^{\frac{1}{2}}Z = 0{\cdot}57$. Adopting as a criterion of resolution $\Delta E/W = 1$, it is seen that when the main peak of energy E is examined, the radiations of next but one, but not of adjacent elements, are resolvable. The width W_e of the escape peak is given by $W_e = a(E - E_K)^{\frac{1}{2}}$, where E_K is the energy of the counter-gas K radiation, hence in this case $\Delta E/W_e = 2bZ/[a(bZ^2 - E_K)^{\frac{1}{2}}]$. Consequently, with a krypton counter, $\Delta E/W_e > 1$ when the primary radiation is the Kα radiation of elements $Z = 39$(Yt) to $Z = 43$; and in the case of a xenon counter $\Delta E/W_e > 1$ when the primary radiation is the Kα radiation of elements $Z = 58$(Ce) to $Z = 66$(Dy).

3. COUNTER CONSTRUCTION

A side-window arrangement with the X-ray beam passing along a counter diameter gives good electrical field geometry together with absence of absorption losses due to counter dead-space. A special feature of the counters used by the author has been the provision of an exit window diametrically opposite the entry window. Hence hard white radiation, or any characteristic radiation not absorbed in the counter gas, can pass straight out of the counter without striking any material which would give rise to fluorescent radiation of wavelength similar to the characteristic radiation it is desired to count. A variety of materials can be used for the counter shell; the author used brass, but this is not the best material to employ when a low background is sought. Gamma-rays from local contamination, and cosmic rays, can excite zinc and copper atoms in the counter walls. The consequent emission of ZnK and CuK radiations gives rise to a component in the background not separable from diffracted CuKα radiation. Beryllium foil is the best window material; mica is the next best, but it is rather fragile and its
surface must be coated with colloidal graphite o
evaporated metal film to render it electrically condu
The dimensions of the argon-filled counters were int
diameter $2\frac{5}{16}$ in. and length 5 in. Both entry and exit wi
apertures were $\frac{1}{2}$ in. × $\frac{1}{2}$ in., and the window frames
designed so that the window material (entry, 0·0
beryllium; exit, 0·002 in. aluminium) was as far as po
coincident with the inner circumference of the cylin
body, and provision was made for pumping on the ou
of the windows so that pressures could be equalized d
evacuation and filling of the counter. The counter a
supported at both ends, was of tungsten wire, 0·00
0·005 in. in diameter. With a filling of argon at a pre
of 75 cm of mercury the calculated efficiency of absor
of CuKα radiation is 0·70.

Use of xenon as the filling gas permits a much smaller
simpler design; a single-ended counter of $2\frac{7}{8}$ in. length
1 in. inner diameter was found to perform satisfac
Since the scanning-plane of the diffractometer was hori
the counter axis was always vertical, and so a single su
for the anode was sufficient. The tungsten anode wire
0·008 in. in diameter, hence it did not need to be ke
tension. The calculated absorption efficiency of CuK
0·74 with a xenon pressure of 20·5 cm of mercury. Spe
scopically pure xenon was used, whereas the argon use
the larger counters was drawn from a tank supply and
purified by passing slowly over heated turnings of copper
calcium. A small quantity of ethylene was included
stabilizing agent in both argon and xenon counters.
could conveniently be purified by fractional distillatio
part of the filling procedure.

4. ELECTRICAL CHARACTERISTICS

It is found in practice that for values of gas multiplica
A greater than about 10 the relation

$$A = p \exp(qV)$$

where V is the applied voltage and p and q are constant
closely followed by stably functioning proportional coun
It is, of course, not essential for proportional counting
the relation between A and V should be of this form;
only required that A be independent of the amount of ion
tion in the counter. Obedience to relation (3) may, howe
be taken as an indication of good counter behaviour.
larger counter described in Section 3, with 1 cm mer
pressure of ethylene added to the argon, obeyed equation
up to $A \simeq 200$. When the pressure of ethylene was increa
to 5 cm, equation (3) was strictly followed up to $A \simeq 50$
the highest gas gain that could be measured. The xe
counter, filled with 20·5 cm xenon and 2 cm ethylene,
obeyed this relation exactly up to $A \simeq 50\,000$. Both
large argon-filled counter with anode diameter 0·00
(hereinafter referred to as design A), and the small xe
filled counter (design B) gave similar values of q, the ave
being $q = 0{\cdot}01$. Thus in both cases a change of A of rou
1% is produced by a change in V of 1 V. This is about
maximum variation in A that can be tolerated when p
height analysis is performed, though somewhat gre
latitude can be allowed in routine diffraction work. Cou
A was operated at about 900 V and counter B at ab
1900 V, so the stabilities of high tension required are res
tively 0·1% and 0·05%. These are within the capabili
of currently available extra high tension units, such as
A.E.R.E. type 1033A.

the counter is used in conjunction with an amplifier of G the output pulse size H is given by

$$H = kGANe/C \qquad (4)$$

re A is the gas multiplication, N the number of ion pairs duced through absorption of the X-ray photon, e the tronic charge, C the effective capacity of counter and first e of the amplifier, and k the factor by which the pulse plitude is reduced by sharp differentiation. The relation- between k and counter variables has been studied by kinson,(10) and from his results the calculated values of k 0·2 and 0·35 for counters A and B, respectively, when a erentiating time constant of 3·2 μs is employed. In this several other respects counter B possesses the better trical characteristics. The value of N is given by $N = E/w$, re E is energy of the X-ray photon and w is the average rgy required to produce one ion pair in the gas concerned. iation of w with E, if any, can be neglected over the range photoelectron energies encountered in diffraction work. ce the percentage of ethylene in the counter fillings is ll, the value of w corresponding to the pure noble gas y be adopted: $w = 27$ eV for argon, from Valentine's(11) asurements with radiation of 2·8 keV. In the case of on, w may be derived by combining Valentine's measure- nts with the ratio $w(\mathrm{Xe})/w(\mathrm{A})$ found by Stetter(12) using onium α-particles, making the reasonable assumption t this ratio is not significantly different for electrons of a keV energy. Thus, for xenon, $w = 27{\cdot}0/1{\cdot}20 = 22{\cdot}5$ eV. ollows that the mean numbers of ion pairs formed in the orption of one CuKα photon in argon and xenon are 298 . 358, respectively. Taking the value of C to be 15 pF, amplifier output pulse H will be $0{\cdot}6\,GA \times 10^{-6}$ V in the e of counter A and about double this amount in the case counter B. Taking 30 V as a suitable size of pulse to be to the pulse analyser, it follows that for counter B the duct GA must be of the order of 2×10^7. Hence for nters of this design, operating satisfactorily at a gas gain 10^4, the electronic amplification required is apparently y 2000. However, experiments described below (Section 6) wed that if uniformity of counter pulse height is to be served at the highest counting rates, then A should not be ed above a few thousand and an electronic gain of not than 10^4 at 1–2 Mc/s should be available.

'wo amplifiers have been used by the author. The first, .R.E. type 1008, has a maximum overall gain of $\times 10^6$, including the hundredfold gain of the pre- plifier. Owing to the high grid resistance of the first stage he pre-amplifier, biasing-off occurred under conditions of counting and high gas amplification. This defect is ly remediable by reducing the value of the resistance. pre-amplifier was mounted directly above the counter. upling between the amplifier and the counter was made a ceramic, 50 pF, thimble-type condenser, rated at 8 kV, counter wire being at high potential. All parts at high ential were completely screened. Provided that the denser was occasionally cleaned with absolute ethanol, trouble due to spurious pulses was encountered.

n later experiments the A.E.R.E. type 1049A amplifier used. This has a maximum overall gain of about 52 000. pre-amplifier, of gain about 3·5, is rather more bulky n that of the amplifier type 1008, but it could be satis- orily mounted on the diffractometer counter-arm. A -post support clamped to the counter-arm ways held the amplifier above the counter. Flexible metal bellows and iding-plate seal between the counter body and the pre- plifier housing provided complete electrical screening and at the same time allowed some latitude in their relative positions. The large bulk of the type 1049A pre-amplifier is due to its containing an extra high tension filter unit. Actually such filtering is not required when a high quality extra high tension supply is used, such as the A.E.R.E. type 1033A, and the connecting cable is of moderate length.

5. PULSE-HEIGHT DISTRIBUTIONS

Pulse-height distributions given by an argon counter of design A have been described(1), and the capabilities of argon-filled counters in discriminating between Kα rays of elements close in atomic number have been summarized.(13) The relative variance of the CuKα main peak pulses was found to be $\sigma^2/\bar{P}^2 = 0{\cdot}0035_6$ (where σ is one standard deviation and $\bar{P}$ the mean pulse height); a slightly lower value, 0·0034, has recently been reported by Arndt, Coates and Crathorn(14) using a continuous-flow argon counter. When calculating the variance of a pulse-height distribution from an experimentally determined pulse-height histogram, Sheppard's correction for grouping should be applied. However, this was not done in the author's experiments: it would only have reduced the variance by about 1–2%.

Fig. 2 shows distributions of pulses in the 200 reflexion from a lithium fluoride crystal set to reflect (a) CuKα characteristic radiation, $\lambda = 1{\cdot}54$ Å, and (b) white radiation of $\lambda = 0{\cdot}77$ Å, obtained with counter B. A copper target X-ray tube was used, operated at 30 kVP in case (a) and 50 kVP in case (b). Analysis of pulses in case (b) was carried down below 8 keV, and quite a large peak was found due to diffuse scattering of CuKα radiation by the lithium fluoride crystal. Since the sensitivity of these side-window counters for various radiations can be exactly calculated, it is clear that the proportional counter is a useful tool for studying the energy spectra of scattered X-radiations. Compared with the argon counter pulse distribution, that of the xenon counter shows a greater separation between main peak and escape peak, and a somewhat smaller size of escape peak, as would be predicted from the data in Table 2. The distributions given by counter B were slightly broader than those of

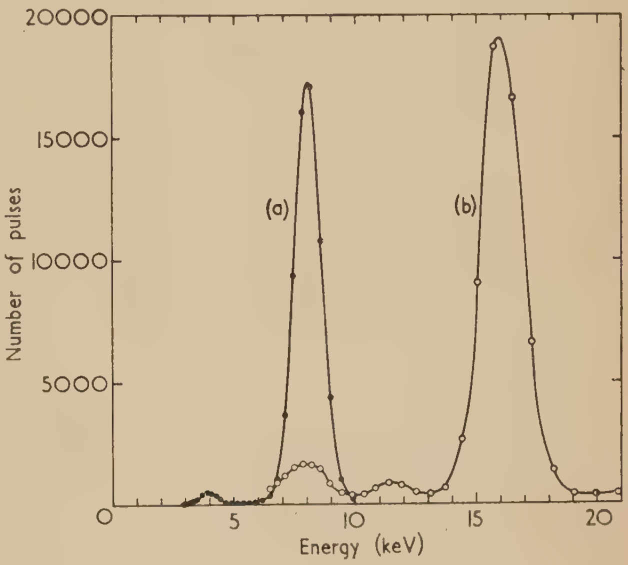


Fig. 2. Pulse-height distributions of xenon-filled counter (a) $\lambda = 1{\cdot}54$ Å, (b) $\lambda = 0{\cdot}77$ Å

counter A, the ratio of widths at half maximum of the CuKα peaks being $1 \cdot 2$. This difference can be ascribed to geometric factors. The bead at the end of the anode of counter B was only a distance of one counter radius below the lower margin of the X-ray beam, whereas for uniform field conditions in the X-ray beam the distance from the beam limits to the ends of the anode should be about a counter diameter(15) unless field-adjusting tubes are used.(16) Counter B was, in fact, constructed to test the performance of a compact single-ended design, and it is seen to possess resolution little inferior to counter A. A common cause of impaired sharpness of peaks is electron loss due to negative-ion formation. Design A is more sensitive than design B to this effect. The criterion that negative-ion formation should produce negligible effects may be taken to be that only a few per cent of electrons having the maximum path in the counter, i.e. traversing the full counter radius, undergo attachment. An electron traversing this distance in counter A makes about 3×10^6 collisions. Likely counter gas contaminants are oxygen and water vapour, which have appreciable electron attachment coefficients(17): an admixture of less than $0 \cdot 1\%$ of either of these would cause a noticeable broadening of the pulse-height distribution. The corresponding electron transit time in counter B is only about 1/100 of that in counter A, so the probability of electron loss is much less, for the same percentage of contaminant.

Considerable interest attaches to the profiles of the pulse-height distribution curves. They are, in fact, slightly skew, decreasing more gradually on the high energy side. This asymmetry is only noticeable on curves practically free from instrumental broadening, since the most common counter defect, electron loss, causes a tail on the low energy side. The variation of height of CuKα pulses observed with counter A can be very well represented by a γ-distribution function which in its normalized form may be written $f = [a(ax)^{b-1} \exp(-ax)]/(b-1)!$ where the mean $= b/a$, mode $= (b-1)/a$, and variance $= b/a^2$. The relative variance of ionization yield of X-ray photons, N, can be represented by the expression $\sigma_N^2/\bar{N}^2 = a/\bar{N}$. In the case of ionization of hydrogen atoms by 1 keV electrons, Fano(18) has calculated the constant a to be $0 \cdot 43$, and has suggested that for other gases, and for energies of the same order, a would be between $\frac{1}{3}$ and $\frac{1}{2}$. Curran, Cockroft and Angus(19) have succeeded in measuring the fluctuation in pulses due to the gas amplification A of single photoelectrons: they found that the relative variance could be expressed as $\sigma_A^2/\bar{A}^2 = b/\bar{A}$, with the constant $b = 0 \cdot 68$. It may be shown that the relative variance in counter pulse amplitude P due to the combined effects of fluctuations in N and A is $\sigma^2/\bar{P}^2 = (a+b)/\bar{N}$, which equals approximately $1 \cdot 1/\bar{N}$ upon substituting for a and b. Taking $\bar{N} = 298$ for CuKα photons in argon, the relative variance observed by the author was $1 \cdot 06/\bar{N}$, and comparison with the above predicted value suggests that the intrinsic limit of energy resolution was effectively reached.

6. PERFORMANCE AT HIGH COUNTING RATES

Pulse-height distributions observed at high counting rates may undergo broadening due to three causes: (i) overloading of the amplifier, (ii) superimposition of pulses, and (iii) reduction in gas gain due to accumulation of space charge. Condition (i) can be overcome by suitable circuit design, in particular by avoiding a high grid resistance in the first stage of the amplifier. The occurrence of condition (ii) can be prevented by sharp differentiation, but it is advisable to make sure that no extra variation of individual pulse siz engendered thereby. Fortunately, the ionization proc in the absorption of X-rays is highly localized. The culated ranges of photoelectrons produced in the absor of CuKα photons in counters A and B are $0 \cdot 4$ and $0 \cdot 75$ respectively, and these may be used as the effective diam of the clouds of initial ionization. The *maximum* lag bet the first and last electrons of such an ion cloud falling the anode will occur for those clouds originating fur from the anode. Making an estimate of the ele mobilities appropriate and neglecting spreading by diffu these lags are calculated to be $\frac{1}{3}$ μs and 1/100 μs in cou A and B, respectively. In the case of counter A it was f experimentally that when amplifier differentiating integrating times were reduced below about $\frac{1}{4}$ μs ther individual pulses became somewhat ragged. Calcu maximum electron transit times in counter A are quite l of the order of 10 μs, but in counter B they are only a $0 \cdot 1$ μs. Thus in counter A it should be possible to some separation between pulses due to the absorption o primary photoelectron and those due to the absorptic AKα radiation not internally converted, since this radi will, on the average, be absorbed at a different counter ra than the original X-ray photon. Hence, with very s differentiation, a slight increase in the relative size of escape peak should be observed. Rough experiments r to look for this effect yielded no significant results.

The above-mentioned localization of ionization is ra disadvantageous from the point of view of production o space charge which causes a noticeable reduction in amplification A when the product of A and the counting exceeds a certain value. A series of experiments was formed with the xenon counter B to test its behaviour at counting rates. The amplified pulses were observed vis on an oscilloscope. This is quite a sensitive metho detecting abnormalities of pulse distributions, since at counting rates the effects of a few pulses exceptionally l or small are exaggerated, owing to the non-linear inte response of both eye and oscilloscope screen, combined duration of after-glow on the screen and persistence of vi in the eye. These observations are summarized in Tab Counting rates were indicated by ratemeter but could nc measured above 10 000 per second. The highest rates probably about 30 000 per second. An A.E.R.E. type 10 amplifier was used.

Table 3. *Behaviour of counting equipment at high coun rates*

Counting rate (counts/s)	*Amplifier gain*	*Gas gain (approx.)*	*differentiating time (μs)*	*Appearance of pu height distributi*
4 000	525	56 000	$0 \cdot 8$	much broad due to s charge.
8 000	5250	4 400	$3 \cdot 2$	broadened, m due to ampl overloading.
>10 000	5250	5 000	$1 \cdot 6$	some broader mainly due pulse superimp tion.
>10 000	5250	5 600	$0 \cdot 8$	very slight br ening.

If the counter is required only to count and not to mea the X-ray photon energy then the disturbances recorde Table 3 would not matter. However, it will be seen that ect choice of operating conditions, i.e. suitable circuits, erentiating time constant not greater than 1 μs and gas not greater than a few thousand, the proportional nter's ability to discriminate as well as to count can be ntained at the highest intensities likely to be encountered X-ray diffraction work.

7. REDUCTION OF BACKGROUND IN DIFFRACTOMETER RECORDS

The low natural background of proportional counters is of cial advantage when weak X-ray intensities have to be asured, as, for example, in the study of thermal diffuse ections. With the pulse-analyser channel set fairly wide as to take in all CuKα pulses the observed background es were 15 counts/min and 3·5 counts/min for counters *A* *B*, respectively. A standard X-ray Geiger counter gave out 60 counts/min in the same location. However, an even ater reduction had been anticipated with the proportional unters, so a study of the energy distribution of background ses was undertaken. Though the low total rate made it ficult to obtain high statistical accuracy it was apparent t both counters showed an increased number of pulses of rgy about the same as that of CuKα radiation, evidently c and copper fluorescent radiation, excited probably by lioactive contamination. A comparison was made with a non counter similar to counter *B* except that it had a copper hode of rectangular cross-section. Due to lack of indrical symmetry narrow pulse distributions were not tained with this counter, and it was usually used with a nple discriminator rather than a single-channel pulse alyser. Yet under these conditions it gave a background only 1 count/min. This counter was over a year old when measurements were made, so short-lived radioactive dies had had time to decay. If a low background is to be tained with a brass-bodied counter it would be advisable cover the interior with a layer to absorb ZnKα and CuKα diations. This could be accomplished by plating with ver, tinning with soft solder or coating with an evaporated n of lead. Cosmic rays produce about seventy ion pairs r cm in argon at normal temperature and pressure.(20) acks passing vertically down through counter *A* will thus ntain about 70 × 9 = 630 ion pairs, the effective length of counter being about 9 cm. Other tracks will produce less nization. Allowing for the differences in pressure and ective length, and taking the ratio of energy loss of cosmic ys in xenon and argon to be proportional to the ratio of mary specific ionization, 1·46,(21) the number of ion pairs a track of maximum length, i.e. parallel to the axis, in unter *B* will be $70 \times 1{\cdot}46 \times (20{\cdot}5/75) \times 4{\cdot}5 = 124$. Thus t only the smaller size of counter *B* compared with counter but also the different energy distribution of cosmic-ray lses, favours lower background in *B* when counting X-rays wavelengths used in diffraction work. As noted above, a all, clean xenon counter will give a background of only out 1 count/min. If a self-rectified X-ray tube is used, a unter gating circuit synchronized with the alternating rent will reduce the background threefold without loss of aracteristic radiation.(22) Combining such a circuit with high-efficiency, xenon-filled, proportional counter, an rease in ratio of X-ray sensitivity to natural background of er 200-fold can be obtained compared with a standard iger counter arrangement.

t is of interest to see what reduction in the background of fraction patterns of light elements is achieved with the oportional counter: the discrimination against fluorescence from heavier materials has already been described.(1, 13) Using a specimen of pure aluminium and a copper-target X-ray tube run at 50 kVP, the background in the vicinity of the 111 reflexion, $2\theta = 38\frac{1}{2}°$, was studied with various detecting arrangements. A nickel β-filter was placed in front of the counter and the background intensity was measured (I) at $2\theta = 35°$, and (II) at $2\theta = 40°$, the former angle lying between the 111 CuKβ reflexion and the nickel absorption edge. The observations, normalized in terms of a peak 111 intensity of 1000 counts/s and corrected for natural background rate, are shown in Table 4.

Table 4. *Analysis of background of Al powder pattern*

Detector arrangement	*Intensity*	
	Position I, 2θ = 35°	*Position II, 2θ = 40°*
a	20	29
b	11·4	20
c	4·2	4·2

In arrangement (*a*) all pulses passing a discriminator set at a level below the CuKα energy were counted, and in (*b*) only those falling within the CuKα channel. In case (*c*) arrangement (*a*) was combined with a diffracted-beam monochromator,(2) a lithium fluoride single crystal. The difference between I*a* and II*a* is the same as that between I*b* and II*b*, and is a measure of the contribution of Bragg reflected white radiation of wavelength adjacent to CuKα. It follows that the difference between rows *a* and *b* is the contribution of hard white radiation. In case (*c*) only CuKα radiation (plus some harmonic radiation) is recorded, and its strength is the same at the two angles. It represents diffusely reflected and Compton-scattered characteristic radiation. The difference between I*b* and I*c* is quite appreciable: it must represent the integrated effect of diffusely reflected and Compton-scattered radiations of wavelength other than CuKα that lie between the nickel absorption edge and the upper wavelength limit of sensitivity of the proportional counter with mean channel height appropriate to CuKα, possibly together with some fluorescent radiation from the filter in front of the counter. It is thus evident that for obtaining the highest purity of recorded diffraction patterns a proportional counter is not as effective as a diffracted-beam monochromator, though even with light elements it will reduce the background to between half and two-thirds of the level observed with a Geiger counter.

ACKNOWLEDGEMENTS

The author wishes to thank Sir Lawrence Bragg and Dr. W. H. Taylor for their interest in this work, and Dr. D. Wilkinson for advice on several matters. Financial support by the British Electrical and Allied Industries Research Association is gratefully acknowledged.

REFERENCES

(1) Lang, A. R. *Nature* [*London*], **168**, p. 907 (1951).

(2) Lang, A. R. *Ph.D. Diss.*, University of Cambridge (1952).

(3) Arndt, U. W. *X-ray Diffraction by Polycrystalline Materials*, Ed. Peiser, H. S., Rooksby, H. P., and Wilson, A. J. C., p. 189 (London: The Institute of Physics, 1955).

(4) West, D. *Progress in Nuclear Physics*, Ed. Frisch, O. R., Vol. III, p. 18 (London: Pergamon Press Ltd., 1953).

(5) Compton, A. H., and Allison, S. K. *X-rays in Theory and Experiment*, 2nd ed. (New York: D. Van Nostrand Co., Inc., 1935).

(6) Burhop, E. H. S. *The Auger Effect*, pp. 30, 31 (Cambridge: The University Press, 1952).

(7) Brown, F., Hanna, G. C., and Yaffe, L. *Proc. Roy. Soc. A*, **220**, p. 203 (1953).

(8) West, D., and Rothwell, P. *Phil. Mag.*, **41**, p. 873 (1950).

(9) Bower, J. C. *Proc. Roy. Soc. A*, **157**, p. 662 (1936).

(10) Wilkinson, D. H. *Ionization Chambers and Counters* (Cambridge: The University Press, 1950).

(11) Valentine, J. M. *Proc. Roy. Soc. A*, **211**, p. 75 (1952).

(12) Stetter, G. *Z. Phys.*, **120**, p. 639 (1943).

(13) Lang, A. R. *Proc. Phys. Soc.* [*London*] *A*, **65**, p. 372 (1952).

(14) Arndt, U. W., Coates, W. A., and Crathorn, A. R. *Proc. Phys. Soc.* [*London*] *B*, **67**, p. 357 (1954).

(15) Rossi, B. B., and Staub, H. H. *Ionization Chamber* *Counters* (New York: McGraw-Hill Book Co., 1949).

(16) Cockroft, A. L., and Curran, S. C. *Rev. Sci. Inst* **22**, p. 37 (1951).

(17) Compton, K. T., and Langmuir, I. *Rev. Mod. P* **2**, p. 123 (1930).

(18) Fano, U. *Phys. Rev.*, **72**, p. 26 (1947).

(19) Curran, S. C., Cockroft, A. L. and Angus, J. *Mag.*, **40**, p. 929 (1949).

(20) Cranshaw, T. E. *Progress in Nuclear Physics,* Frisch, O. R., Vol. II, p. 271 (London: Perga Press Ltd., 1952).

(21) Korff, S. A. *Electron and Nuclear Counters* (York: D. Van Nostrand Co., Inc., 1946).

(22) Wooster, W. A., Ramachandran, G. N., and Lan *J. Sci. Instrum.*, **25**, p. 405 (1948).

An analysis of injection phenomena in the Birmingham proton synchrotron

By C. A. Ramm, Ph.D., A.Inst.P.,* R. F. Coe, M.Sc., Grad.Inst.P.,† and T. B. Vaughan, B.Sc., University of Birmingham

[*Paper received* 19 *August*, 1955]

Experimental analysis of the injection processes in the Birmingham proton synchrotron shows that the machine accepts particles for the whole of the theoretical time of injection and that the radio-frequency system accelerates only those particles with very small betatron oscillations. Injection with rising energy gives an increase of more than twice the intensity of the machine output compared with constant energy injection.

Although further practical information about injection phenomena in the Birmingham proton synchrotron(1) will continue to accumulate slowly, the machine is now being used almost entirely for fundamental research and it is no longer economical to devote appreciable operating time to technical studies. It seems justifiable, therefore, to publish this account of injection researches, despite incompleteness, since the existing data may be of some use in the design of other machines.

Even simple experiments with a proton synchrotron can demand a large expenditure of time and effort. The authors hope that the reader will appreciate this contributory cause to the poor range and statistics of some of the results. Rather than attempt to indicate probable errors in the experiments the authors have shown the experimental points for the various curves.

THE RADIAL VARIATION OF THE PROBE SIGNAL

A description of the injection equipment and an analysis of the proton trajectories during injection have been given elsewhere.(2) It was shown that for a particular position of current collecting electrode P_I, a characteristic signal could be obtained from which an injection analysis could be made. With the probe at an azimuthal distance of $\pi(1-n)^{-\frac{1}{2}}$ (where n is the magnetic field index) from the tip of the guide electrodes, the signal as observed on an oscilloscope consists of two components, the main spike due to the direct collection of the injected beam, and a component due to the spiral beam which has made more than one revolution of the or

For an injected beam of zero width, the time t of ar of the first particles at the probe P_I, using the same notat as previously,(2) is

$$t = (d - c\Delta r/2)/2\dot{r}$$

where d is the effective horizontal semi-aperture of the vacu box;

Δr is the shrinkage of the mean orbit per revolution;

$\dot{r}$ is the time derivative of the radius of the mean orb

c is a constant $= \pi(1-n)^{-\frac{1}{2}}$ in this case, and $t =$

the instant at which the mean orbit shrinks past the tip the guide electrodes. The experimental precision does warrant the extra complication in analysis of acknowledg the variation of $\dot{r}$ with radius. For a beam of finite width at entry the first particles which reach P_I are those wh entered through the guide plates at maximum radius. these

$$t = (d - 2w - c\Delta r/2)/2\dot{r}$$

As the azimuthal position is kept constant, but the rac position of the probe is moved out from the inner wall the vacuum box, the time t of first appearance of the m spike is reduced, as is the persistence of the signal due to spiralling beam. This is shown schematically in Fig. 1 which the probe signals are tracings from actual oscillogra photographs. When the radial position of the probe further out than the effective mean radius of the distar from the guide electrode tip to the inner wall, a third sign appears, provided that the probe is not very wide. In su ions there are two possible types of trajectories which t in direct beam falling on the probe and producing a l similar to the main spike. For the particular azimuthal ion chosen this third signal can be very large, as will be at the higher values of the radius in Fig. 1. From 1 the effective radial velocity of both the main spike the last of the spiralling beam can be measured, and one quite accurately the expected difference of a factor of If d is known it is possible to evaluate $(1 - n)$ by tituting the value of $\dot{r}$ in the equation

---

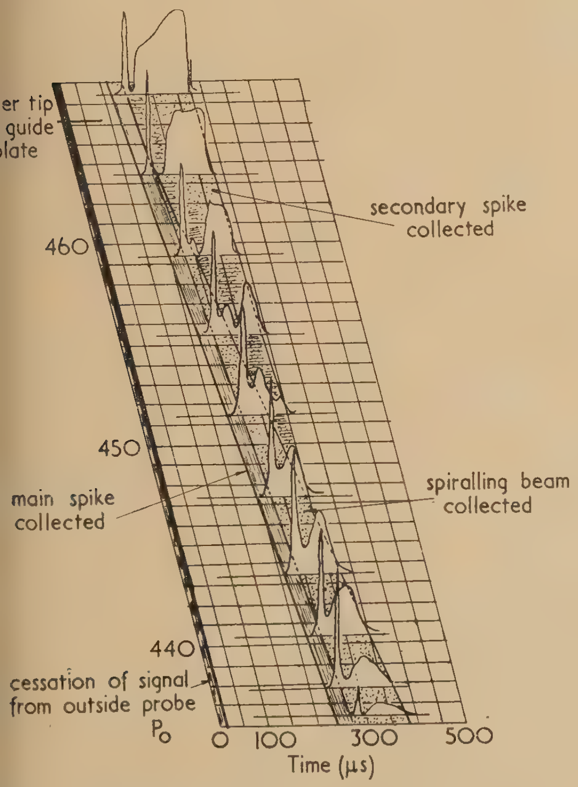
* Now at CERN Proton Synchrotron Group, Geneva, Switzerland.

† Now at Joseph Lucas (Electrical) Ltd., Birmingham.

$$\dot{r} = -\frac{r_0 \dot{B}_0}{(1 - n)B_0} \tag{3}$$

re B_0 is the value of the magnetic field at the mean orbit adius r_0. For this machine at injection we compute from r of the velocities a value of $n = 0{\cdot}75$. If the time of tion of the main spike is divided by $2\dot{r}$ the quotient esents the width of the probe together with twice the h of the beam at the probe. It is inferred from Fig. 1, his method, that the average width of the beam at P_I is ut 15 mm, which is 7 mm greater than the gap between guide electrodes. From direct visual observation on a nescent target at the probe position it appears that the cal extent of the direct beam is about the same.

has been shown previously (Ref. 2, Fig. 2) that if a e is situated near a nodal point, then every particle h is injected into the machine and which can circulate ast once, can be collected in either the main spike or the ndary spike. In this machine the probe is near to the ect azimuthal position and collects almost all particles n its edges are at the limits $r = 467$ and $r = 465$ cm Fig. 1).



g. 1. Oscillograph traces showing variation of injected beam with radial position of the probe

THE EFFECTIVE WIDTH OF THE INJECTED BEAM

By measuring the charge collected from the spiralling beam it is possible to assess the effective width of the injected beam at any instant of injection, and hence it is possible to determine the function w of equation (2). Fig. 2(*a*) shows the number of spiralling protons collected at various radial positions of the probe P_I. It is emphasized that no importance should be attached to the absolute magnitudes quoted for proton numbers, as these refer specifically to the conditions and alinement under which this analysis was made. By differentiating the curve of Fig. 2(*a*) a function is obtained which represents the rate of increase of circulating charge shown in Fig. 2(*b*). The fact that this function has negative values in some regions of the vacuum box merely indicates beam loss. From measurements of the peak current in the main spike for radial positions of the probe near to the tip of the guide electrodes, it is possible to scale the derivative in terms of the effective width of the injected beam, assuming uniform beam density. This it may be inferred that at the commencement of injection, under the conditions of analysis, less than 20% of the injected particles could actually spiral. In the interval from first acceptance until the beam loss developed, the average fraction of the injected particles which could spiral was about 25%. An independent confirmation of this average may be obtained directly from Fig. 3, in which is shown, to the same scale, the number of protons collected for various probe positions for both the circulating particles and those in the secondary spike. For the best probe positions some four times as many particles could be collected from the secondary spike compared with the circulating beam. From the product of the peak current associated with the main spike and the possible

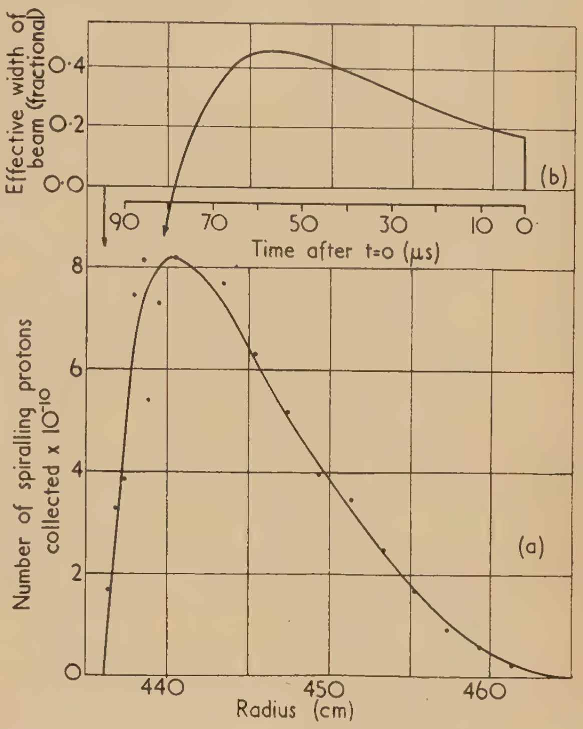


Fig. 2. (*a*) Number of spiralling protons collected at different radii. (*b*) Variation of beam width across vacuum box

time of circulation, the same absolute number of protons is obtained as is collected in the secondary spike, to within the experimental limits of error. From these results it is inferred that a significant loss of particles occurs in this machine at the inner guide electrode, and furthermore that the effective width of the injected beam increases over a range of about a factor of two in the first 60 μs. However, this is not of practical interest, for the radio-frequency system will only accept those particles which enter the machine within a few microseconds after $t = 0$.

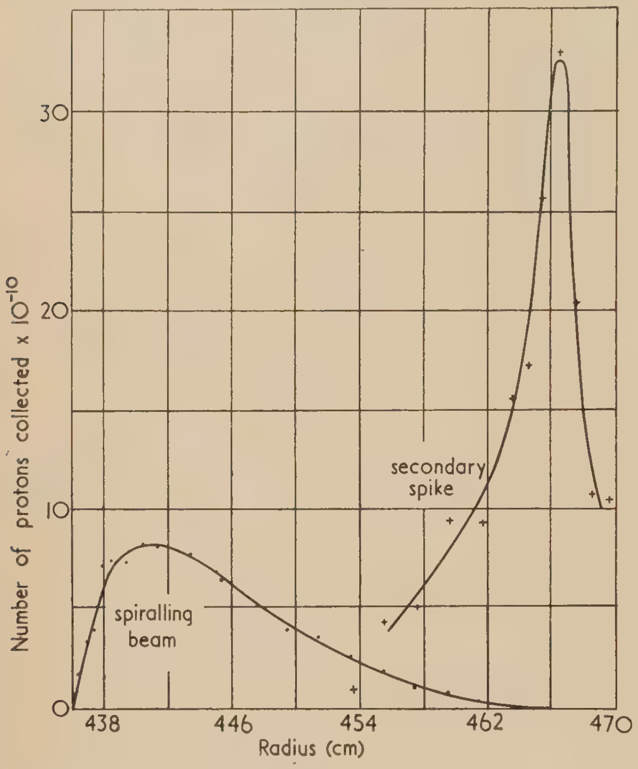


Fig. 3. Total number of protons collected by probe P_I at different radii

INFORMATION OBTAINED BY INTERRUPTION OF THE BEAM

In their very interesting report$^{(3)}$ the Brookhaven experimenters described a system for modulating the injected beam so that short pulses could be used for trajectory studies. The present authors have used less elegant circuitry to produce a form of beam suppression for various analyses. It is possible to modulate the power supply unit for the guide electrodes so that a trapezium-shaped pulse of variable duration may be applied to interfere with the injection alinement. Being free from the necessity of energy stability it is more convenient to suppress portions of the beam rather than to inject short pulses of beam, for, by not interfering with the injected beam under normal circumstances, the signal from the probe P_0, at the outer wall of the vacuum box, is always available for a reference time mark. Fig. 4 shows a series of tracings of six actual photographs from a double-beam oscillograph, which was triggered in each case from a signal from P_0. The lower trace represents the modulating voltage on the guide electrodes, which had been applied successively later in each diagram, whilst the upper trace shows the signal from P_I. It is interesting to note
as the beam was disturbed at various times during injec
the pattern due to the spiralling beam changed. The
metry of injection time and collection time about the
spike is clearly shown. Tracings (1) and (6) show the no
undisturbed signal from P_I.

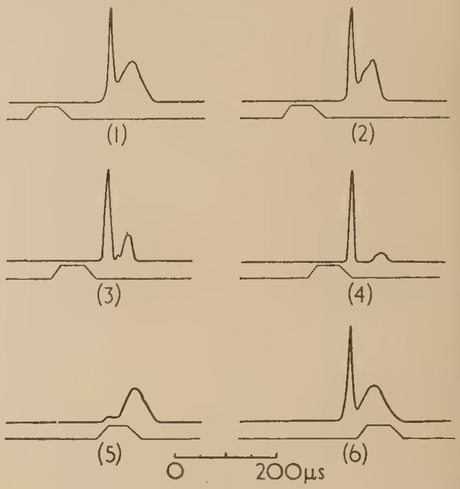


Fig. 4. Oscillograph traces showing suppression
injected beam by modulation of guide electrode pote

By using a similar technique it is possible to inve
that part of the injection cycle during which particles,
are acceptable to the radio-frequency accelerating vo
enter. Results from a typical experiment are shown in
A trapezium-shaped modulating pulse of half-width a
55 μs was applied to the inner electrode of the guide p
which is normally held at earth potential. Fig. 5(*a*) s
the relative charge collected by P_I from spiralling pr

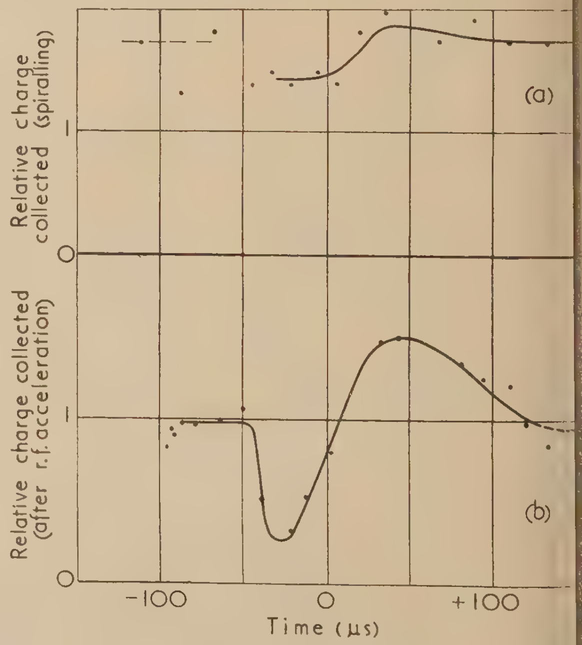
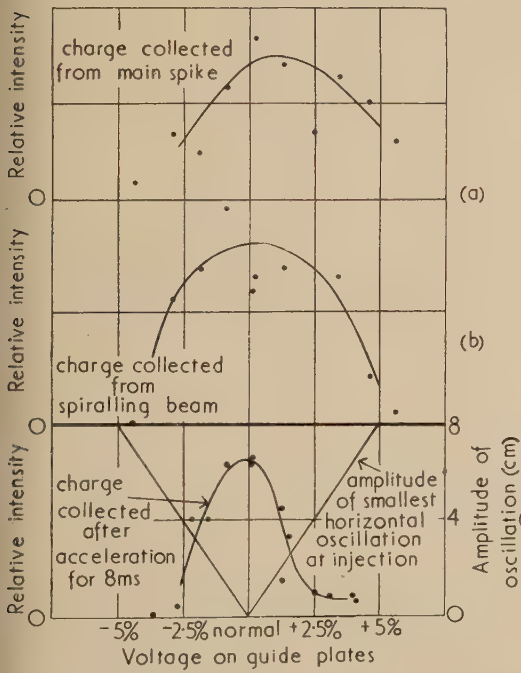


Fig. 5. (*a*) Intensity of spiralling beam as a function
time of guide electrode modulation. (*b*) Beam accept
by radio-frequency as a function of time of guide electro
modulation

s the time difference between the trailing edge of the ulating pulse and the leading edge of the undisturbed spike. As the modulating pulse is moved through the tion interval a slight decrease of the spiralling beam is ted. In Fig. 5(*b*) the results have been obtained with the pulse length, and the charge collected after about of the radio-frequency acceleration is shown. It is ous that as soon as a disturbance is felt by the beam ing very close to the time at which the mean orbit ks past the tip of the guide electrodes, a very serious loss celerated particles occurs. It is difficult to interpret the e precisely because of the shape of the modulating pulse, t may be deduced that only those particles with horizontal lation of amplitude less than 5 cm are accelerated by the -frequency system. An interesting and unexpected effect rs when the modulating pulse cannot possibly interfere the beam during actual injection. If the modulation is ied to the inner guide plate after the mean orbit is half- across the vacuum box an increase in accelerated beam rs. This result is not fortuitious and is repeatable, but explanation in terms of the effect on particle trajectories not yet been found. It could be believed that this omenon was present, to a lesser extent, in Fig. 5(*a*) for case of the spiralling beam. The same effect is not eved by applying a steady voltage to the inner electrode.

AM VARIATION WITH GUIDE PLATE VOLTAGE

confirmation of the inference drawn in the previous on, namely, that only those particles with very small initial zontal oscillations are acceptable to the radio-frequency leration, comes from a direct study of the effects produced arying the overall guide electrode voltages. Fig. 6 shows results of a series of experiments. Fig. 6(*a*, *b*) are self- anatory and show, within the large limits of the experimental errors, that around the optimum working voltage a change of the guiding field of the order of 1% produces no very marked effect on either the main spike or the amount of spiralling beam. In fact, for the dimensions of the particular electrodes here a change of this magnitude has very little influence on the effective aperture of the electrodes, since it merely deflects the beam by about 0·002 rad relative to the usual direction. However, small changes in the guiding field have quite important effects on the amount of beam which can be accelerated, as is shown in Fig. 6(*c*). It is inferred that this is due to the fact that the amplitude of oscillation introduced by the departure of the guiding field from normal is undesirable. In fact, a departure of 1% introduces a minimum oscillation of 1·6 cm in the spiralling beam, which effectively means that the type of trajectories normally entering between $t = 0$ and $t = 3$ μs are missing. If Fig. 6 is interpreted in the simplest form, assuming that the optimum guide plate voltage corresponds to tangential injection, it is concluded that particles with amplitudes of oscillation greater than about 4 cm are quite unsuitable for the radio-frequency acceleration. This loss of particles has been discussed further by other workers in this laboratory.(4)



ig. 6. Beam intensity as a function of guide electrode voltage

(*a*) After one revolution.
(*b*) Spiralling beam.
(*c*) Beam accepted by radio-frequency voltage.

THE TIME OF RADIO-FREQUENCY GATING

It is of technical importance that the principles involved in determining the instant of radio-frequency gating should be borne out by an experimental test. Fig. 7 shows the variation of charge collected at P_I after acceleration for about 8 ms by the radio-frequency system *versus* the time of gating of the radio-frequency.

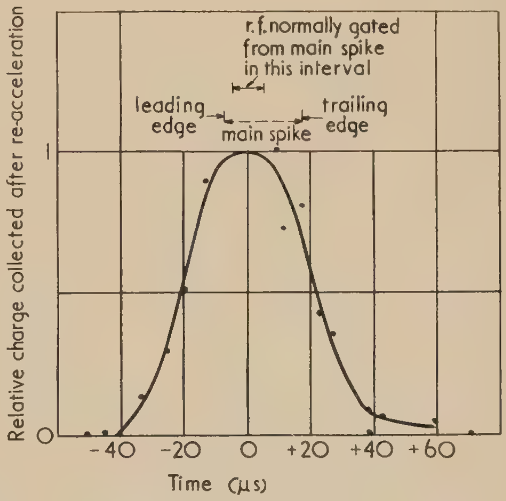


Fig. 7. Variation of accelerated beam with a time of radio-frequency gating

For normal automatic running the characteristic signal is supplied to the radio-frequency control room where, to remove unwanted interference and because the signal from the probe amplifier is conveniently large, a simple discriminator is used. As soon as the signal from the probe amplifier rises above a certain level the radio-frequency acceleration is switched on. Thus acceleration always commences before the peak of the main spike, the precise time depending on the amplitude of the injected beam. The range in time over which acceleration commences is shown in Fig. 7 and it will be seen that, within the limits of experimental error, this coincides with the optimum time for acceleration. An error in timing of ± 1 μs would be significant and this would mean that an absolute stability of better than about 0·15% in injection energy would be required if the radio-frequency gating was initiated at a programmed time in the magnet cycle.

It is of interest to notice that since, at injection, $\dot{r} \simeq 10^5$ cm/s, the abscissa on Fig. 7 may be read in millimetres instead of microseconds and the curve then refers to the position of the mean orbit, corresponding to the injection energy, relative to the mid-position in the vacuum box.

THE APPLICATION OF RISING ENERGY

The horizontal injection oscillations which result in such a significant loss of particles, may be reduced by modulating the energy to match the magnetic field during the injection interval.(5)

As soon as the technique of rising energy is applied to injection there arises in principle the possibility of a large number of technical experiments. Very few of these have been done, because of the limitations mentioned at the beginning of this paper, but enough investigation has been made to show that the technique is worth while.

For reasons outlined in the previous paper(2) the nature of the characteristic signal is considerably changed as soon as a rate of rise $\dot{E}$ is applied to the injection energy. In practice, the rate of rise is not completely uniform and the resultant signal from the probe P_I is complex. Conditions are further complicated by the extra scatter in the results, introduced from slight fluctuations in the rising voltage equipment. Thus the statistics are poor.

It is proposed to describe briefly only a few of the analyses. Fig. 8 shows the amount of charge collected due to protons spiralling to the probe P_I, near the inner wall of the vacuum box, *versus* $\dot{E}$. The rate of rise of energy was triggered by a delayed signal from P_0 soon after the instant that the mean orbit passed the tip of the guide electrodes. The curve has a shape which would be expected from the elementary theory, and, in particular, above a critical value of $\dot{E}$ the spiralling beam vanishes. That this vanishing of the beam does not occur even more sharply with a rise in $\dot{E}$ is probably due to the lack of precision in the triggering and to the departure of $\dot{E}$ from a constant value.

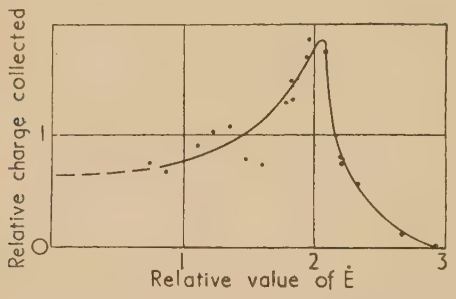


Fig. 8. Intensity of spiralling beam as a function of rate of rise of injection energy

If a value of $\dot{E}$ is chosen just a little below the critical value it is found that the optimum instant of gating for radio-frequency acceleration is not critical, as is shown in Fig. 9. The abscissa of this figure shows the interval between the trailing edge of the signal from P_0 and the instant of gating the radio-frequency acceleration. The magnitude should be contrasted with the corresponding diagram, Fig. 7, for injection at constant energy.

Thus Fig. 9 establishes the principle that for the opti value of $\dot{E}$ the instant of radio-frequency gating can between useful limits. Advantage is taken of this operating the rising energy equipment and a time of ra frequency gating is chosen well after the mean orbi shrinks past the guide electrodes. Then by adjusting rate of rise, triggered from the correct instant, a condit found in which the magnitude of the accelerated beam an optimum. Such a process is shown in Fig. 10.

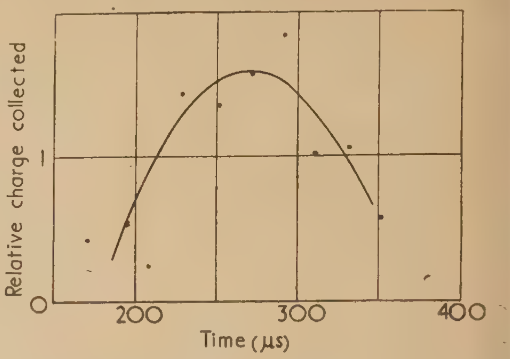


Fig. 9. Dependence of accelerated beam on time radio-frequency gating with optimum rising injecti energy

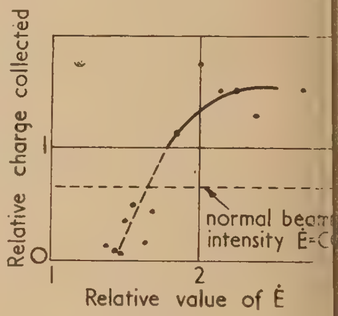


Fig. 10. Intensity of accelerated beam as function of rate of rise of injection energy

precise shape of the curve has no great significance and i from zero, not because the beam is unsuitable for accelera but simply because the gating instant is too late. As the of rise reaches a value in which the vacuum box is filled a long time with spiralling beam with small horizo oscillations, the accelerated beam reaches an optimum va which has been found to be about 2·5 times more than beam accelerated with fixed energy injection. The magnit of this factor alone has justified the effort spent on equipment.

ACKNOWLEDGEMENTS

The authors acknowledge gratefully the encouragem received from Prof. P. B. Moon to continue these studies also the co-operation of the other members of the chrotron team. Valuable assistance with the photograp processing of innumerable oscillograph traces has been gi by Miss B. Hillman.

REFERENCES

(1) *Nature* [*London*], **172,** p. 704 (1953).
(2) Ramm, C. A. *J. Sci. Instrum.*, **33,** p. 52 (1956).
(3) Blewett, M. H., and others. *Rev. Sci. Instrum.*, p. 861 (1953).
(4) Riddiford, L., Van der Raay, H. B., and Coe, R. *Proc. Phys. Soc.* [*London*] *A*, **68,** p. 489 (1955).
(5) Le Caine, H. Ph.D. Thesis (University of Birmingh 1952).

A precision high-temperature specimen chamber for an X-ray diffractometer

By G. K. Williamson, B.Sc., Ph.D.,* and A. Moore, B.Sc., Ph.D., Grad.Inst.P.,† University of Birmingham

[*Paper first received* 19 *July, and in final form* 28 *October*, 1955]

A high-temperature specimen chamber is described in which continuous gas circulation is employed in heating a specimen 1 in. diameter × 0·020 in. thick to a uniform and accurately known temperature. Using techniques sensitive to 0·1° C no temperature differences could be detected between the centre and periphery of the specimen in the range 20–200° C and the difference had a maximum value of less than 1° C at 600° C. In practice the true temperature of the specimen can be measured throughout the range 20–650° C. Temperature fluctuations due to the control circuit never exceeded ±0·5° C as measured on the specimen. The general reliability of the chamber has been critically examined. Slight modification to the instrument should raise the maximum attainable temperature to approximately 900° C.

relative advantages of counter diffractometers and film niques for recording diffracted X-ray spectra are now y well known.(1–3) The principal advantage of the actometer in high-temperature studies is the speed with ch approximate results can be refined: the appearance of w phase is quickly detected in a few minutes by measure- its at the position of a known strong reflexion from this se, and the extent of the transformation can be calculated fair precision from the measured intensities. The dis- earing phase method of determining phase boundaries is, efore, both quicker and more accurate when used in junction with a diffractometer rather than with films.

owever, the value of a diffractometer lies in the very high cision (better than 1 %) with which intensity measurements be made, and to make full use of this the temperature of specimen must be known and controlled to within very limits.

urnaces for use with diffractometers have already been ribed(4–7) in which the specimen is heated by radiation /or thermal conduction through a block of comparatively e thermal mass. Despite the presence of the attenuating mal mass adjacent to the specimen, both the thermal lients and temperature fluctuations of the specimen are rted to be large, namely 5° C/cm^2 and ±2° C respectively. se thermal properties have been re-examined in an erimental design, with a precision technique,(8,9) to stigate the possibility of improving the thermal racteristics in this type of furnace.

or this purpose a nickel powder specimen 0·5 mm thick pressed into a machined recess in the surface of an electric- heated copper block. A radiation shield adjacent to the surface of the powder minimized heat loss by radiation, the whole assembly was enclosed by a refractory con- er. Gradients as large as 600° C/cm were found through thickness of the specimen and as much as 6° C/cm along surface at 500° C. The magnitude of these gradients, bined with difficulties of fine temperature control and accurate measurement of specimen temperature, made it erative that an alternative design was investigated, and lly one in which the specimen is immersed in a heated ulent gas was adopted and developed. Gaseous atmo- eres are limited to those which do not appreciably absorb ays and do not react with the specimen. Suitable media hydrogen, helium, nitrogen and, if at low pressure proximately 1 cm of mercury), argon.

DESIGN OF THE SPECIMEN CHAMBER

The most important features of the design are shown in Figs. 1–3.

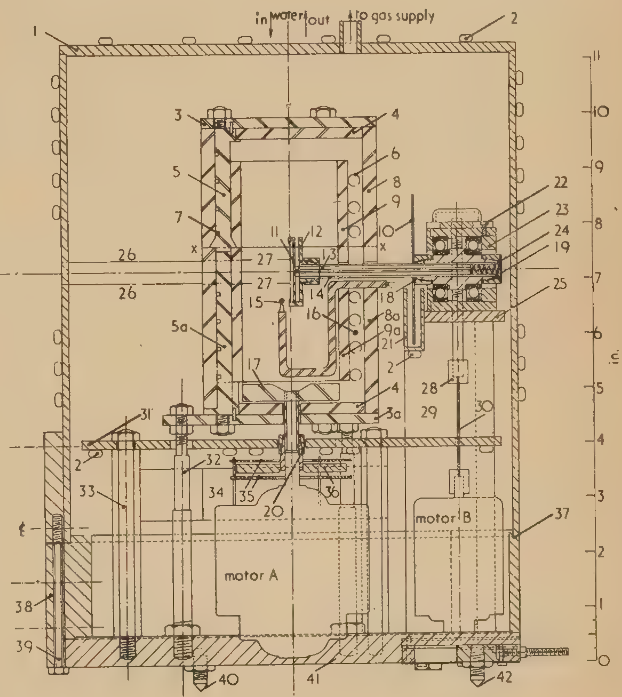


Fig. 1. Sectional view of specimen chamber

1, vacuum tight lid; 2, water-cooling; 3, 3*a*, furnace end plates; 4, furnace end plates (silica); 5, 5*a*, spacers with slots 7 for heater 6; 6, helical heater; 7, slots in spacers; 8, 8*a*, outer silica tube; 9, 9*a*, inner silica tube; 10, reflector, cooled in oil bath 21; 11, spring loaded disk; 12, specimen holder; 13, silica tube transmitting thrust from spring located against movable plate 24 to disk 11; 14, silica tube supporting specimen holder 12; 15, measuring thermocouple, Pt: Pt/13 % Rh; 16, position of temperature controlling thermocouple (chromel/alumel); 17, centrifugal fan (Ninomic 70); 18, 19, 20, collett chucks; 21, oil bath; 22, housing for specimen rotation bearings; 23, bearing thrust collar (magneto type bearings); 24, end plate; 25, supporting table; 26, 27, slots for passage of X-ray beam; 28, flexible drive coupling; 29, legs supporting bearing housing 22 on table 25; 30, Bowden cable forming a flexible transmission from motor *B*; 31, water-cooled radiation shield; 32, pillars supporting furnace base plate 3*a*; 33, pillars supporting shield 31; 34, terminal board; 35, casing for 36; 36, centrifugal fan (copper) for dissipation of heat conducted along the shaft of motor *A*; 37, "O" ring seal; 38, casing for lid retaining bolts 39; 39, lid retaining bolts; 40, legs (2); 41, base of specimen chamber; 42, movable leg.

Now at Atomic Energy Research Establishment, Harwell, ks.

Now at Atomic Weapons Research Establishment, Alder- ton, Berks.

The furnace. The furnace consists essentially of two concentric silica tubes (8, 8*a*, and 9, 9*a*), supported on the furnace base plate (3*a*) (Nimonic 70 by H. Wiggin and Co. Ltd.). Three Nimonic spacers (5), 120° apart, serve to position the inner furnace tube relative to the outer tube. The helical heating element (6) (Brightray C by H. Wiggin and Co. Ltd.) is suspended in insulating silica beads from the slots (7 in the outer edges of the spacers.

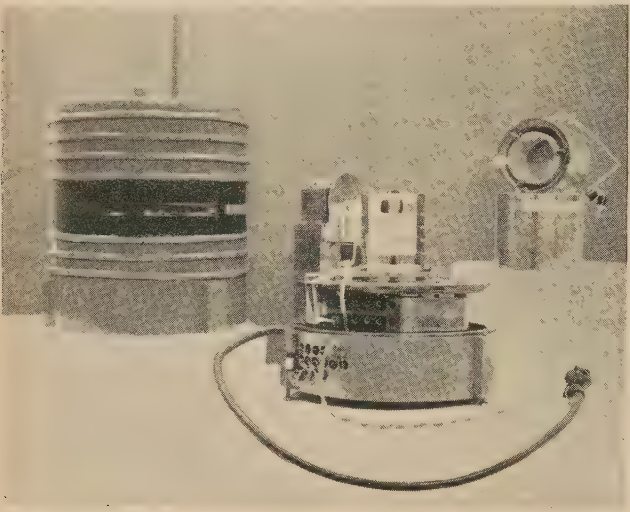


Fig. 2. The specimen chamber partly dismantled showing on the left the vacuum-tight lid with slots covered with cellophane and in the centre the main assembly with the upper half of the furnace and the outer lower silica tube removed. These latter components are shown on the right. For clarity both the inner and outer aluminium foil windows are discarded. The specimen holder can be seen through the slots cut in the inner silica tube, and the centrifugal fan between the bottom of this tube and the silica disk. Note the general arrangement of the helical heater against the inner silica tube and between the two silica tubes forming the upper half of the furnace. The controlling couple is shown in position in the centre of the lower furnace windings

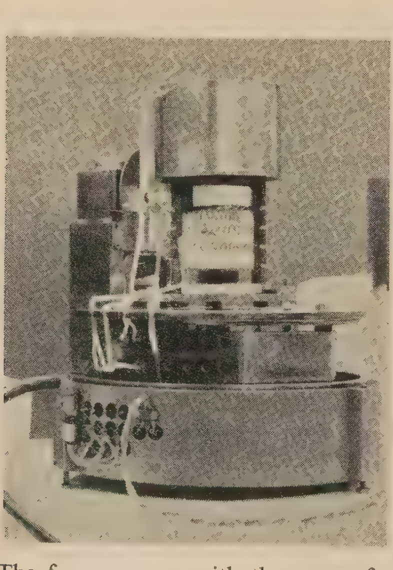


Fig. 3. The furnace zone with the upper furnace and inner window in position. Note the electrical connexions to the terminal board beneath the water-cooled radiation shield

A gas is circulated continuously through the hea element and the inner furnace zone by the centrifugal fan (speed 2000 rev/min). There is in consequence, there only a negligible proportion of heat transferred directly the element through the silica tube (9, 9*a*) to the furnace thus the geometrical arrangement of the element h negligible effect on the temperature distribution.

To enable the upper portion of the furnace assembly t removed and in turn to facilitate access to the speci holder (12), the furnace tubes and the spacers (5, 5*a*) split at *XX* (Fig. 1). The heating element (6) is also div at *XX* and the two portions joined in series, the elect connexions being made at a terminal board (34). The u portion of the furnace locates in position by pegs on eac the spacers (5) which locate in slots cut in the correspon lower spacers (5*a*). The upper silica tubes (9) and (8) supported by the dovetails at the base of the spacers while the insulating silica disk (4) rests on three project at the top of these spacers.

Slots (27) cut in the silica tubes over an angle of 180° a passage of the X-rays at all Bragg angles. Thin foil win (at present 0·0005 in. aluminium) are readily inserte "runners" spot welded to the polished nickel radiation s surrounding the tube (8, 8*a*) and into a nickel foil fr which can be clipped around the inner silica tube. T windows need not be vacuum tight, their purpose bei prevent serious "short circuiting" of the gas flow, and in ference of the surrounding cooler gas on the therma tribution within the furnace. The windows can be e replaced if damaged.

The specimen holder. The invar specimen holder clamps on to the silica shaft (14) which can be rotated thro a worm drive from motor *B*. Silica has been used to re to a minimum the effect of thermal expansion of the shaf the position of the specimen relative to the diffractometer. to minimize the effect on the thermal distribution in furnace of heat lost by conduction along the shaft. specimen, in the form of a flat disk approximately 1 in diameter locates against the inside of the flange on specimen holder and is held in position by a spring loa disk (11). The spring is inside the "cold" end of shaft and its thrust is transmitted by a thin silica tube (13). spring loading can be relaxed by swinging the end plate from the end of (14) when the specimen can be remo through the slot in the specimen holder (see Fig. 1).

Control and measurement of specimen temperature. chromel/alumel controlling thermocouple (16) is pla between the two silica tubes, (8, 8*a* and 9, 9*a*). The positi ing of this couple is unimportant, so long as it is in a posit of high turbulence and thus sensitive to changes in fur temperature.

The true temperature of the specimen is measured by platinum/platinum-13% rhodium thermocouple (15) adja to the specimen holder. Critical examination has sh there to be no detectable temperature difference between specimen and the adjacent atmosphere for the tempera range 20–600° C. To eliminate the effect of heat conduct along the thermocouple leads upon the temperature of hot junction, the thermocouple is arranged with a 4 length within the heated zone.

Ancillary equipment. The specimen shaft is held in bearings by collett chucks (18 and 19). Any slight "pl in the bearings as a result of wear can be removed by tigh ing the thrust collar (23). The chromium plated cop

(10) on the front of the collet chuck (18) runs in a water- ed oil bath (21) to prevent the radiation or conduction eat to the ball races.

oth the fan motor A and the specimen rotation motor B housed under a water-cooled radiation shield (31). A nd centrifugal fan (36) attached to the fan motor shaft w the water-cooled radiation shield, dissipates any heat ducted down the shaft from the furnace.

ith the exception of the measuring thermocouple, all the ssary electrical connexions are made through glass–metal s in the base of the chamber. For general convenience various electrical connexions to the glass–metal seals are le at a terminal board (34). In the case of the platinum–dium thermocouple the leads are taken directly to a ntiometer through wax seals. This latter arrangement inates any possibility of the generation, by electrical tact at a glass–metal seal, of extraneous electromotive es.

he outer copper chamber is water-cooled and is clamped he base (41) by three bolts (39). Vacuum sealing is effected an O-ring (37) enabling the whole chamber to be austed and filled with a suitable inert atmosphere. A slot, ed with 0·001 in. cellophane permits entry and exit of X-ray beam over the range 180° 2 θ. A sliding leg of matic design is built into the base of the instrument and vides easy means for centring the specimen on the ractometer.

se of the specimen chamber. The furnace is operated n a Variac and the temperature controlled with an er–Wheelco Capacitrol controller switching in and out an rnal resistance (approximately 15 Ω) wired in series with heating element (6), (70 Ω). The furnace has been used sfactorily with both air and helium. In the case of helium, d with reactive samples, the chamber has been filled to htly greater than atmospheric pressure and the enclosed nosphere continually "gettered" with a heated coil of nium wire.

CHARACTERISTICS OF THE FURNACE

eneral. In practice the furnace temperature is very ble and responds rapidly to changes in adjustment. The ree of temperature control is such that fluctuations of gas perature never exceed ±0·6° C with a control period of roximately 15 s, and the fluctuations of specimen perature are even less than this value. The drift of the n furnace temperature over a period of 30 h at 300° C ess than 0·3° C. The maximum temperature attainable mited to 600° C (500 W input) at present, because of the of aluminium foil windows. It is expected that a tempera- of approximately 900° C will be obtained when beryllium dows are substituted.

hermal gradients. Thermal gradients have been measured g very fine thermocouple wires (0·003 in. thick) in order ninimize any effects due to conduction along the length he wire. Temperature differences between the centre and es of a dummy specimen have been measured in both izontal and vertical directions. The results are shown in 4; the solid line indicates the horizontal and vertical perature difference over 0·5 in., while the dotted lines the limits of the temperature fluctuations over the surface he specimen during a cycle of the temperature controlling em. It is not expected that these figures are appreciably ced on a rotating specimen.

eliability of the specimen chamber. Relative movement ween the specimen and the diffractometer due to thermal expansion of either the silica shaft or the specimen holder has been measured from a study made on aluminium. This study was confined to the {111} profile using monochromatic CuKα radiation. A low angle ($\theta \simeq 16°$) reflexion was chosen for two reasons, for small relative movements of the specimen, the angular shift of the diffracted beam (at constant temperature) is a maximum at low angles, and similarly the exposed area of the specimen is large near glancing incidence and therefore the presence of thermal gradients in the specimen would be easily detected.

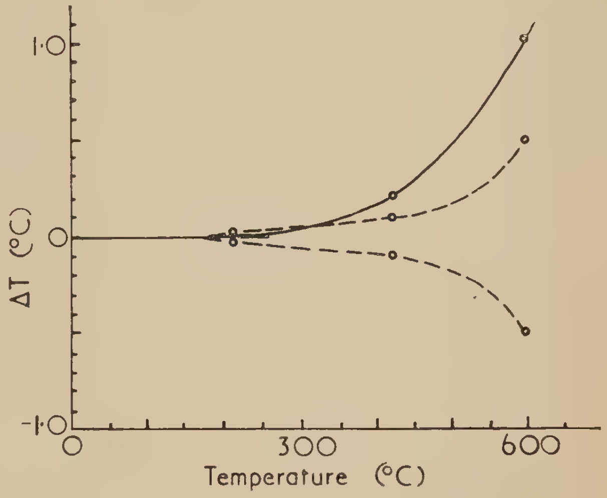


Fig. 4. The temperature of the specimen at points upon its surface during a control cycle of the temperature controlling system

——— = temperature (°C) difference between centre and edge of specimen.

– – – – = fluctuation in temperature at centre and edge of specimen during a control cycle.

The shift of the {111} reflexion has been determined to within 1 minute in 30 minutes of arc. The calculated coefficient of expansion for the range 20–600° C is $2 \cdot 59 \times 10^{-5}$ and compares favourably with the accepted value of $2 \cdot 60 \times 10^{-5}$. The discrepancy of $0 \cdot 01 \times 10^{-5}$ lies within the experimental error (for {111} reflexion) of $\pm 0 \cdot 015 \times 10^{-5}$ and exceeds by a factor of four the error arising from the thermal shift (0·000 07 in.) of the silica tube (14, Fig. 1).

To give direct evidence with regard to temperature gradients, the following transformation

$$\alpha' \rightleftharpoons \alpha + \beta$$

occurring in the aluminium/zinc binary system has been studied. This particular eutectoid transformation was selected since both its kinetics and transition temperature have been thoroughly investigated.[(10)] An alloy containing 60% wt zinc was chosen to minimize the effect of any loss of zinc. The progress of the transformation was obtained directly from intensity measurements on the strong (10·1) β reflexion. At 277·5 ± 0·5° C it was found that the intensity of the reflexion decreased at a rate corresponding to a 10% loss of β in the first hour. Decreasing the temperature to 276 ± 0·5° C was sufficient for the reaction to be immediately reversed. The reaction rapidly proceeded to 90% completion in the forward direction on raising the temperature to 279 ± 0·5° C. These figures agree with, and represent a refinement of, those already obtained[(10)] by indirect methods which give the transformation temperature as 275 ± 2° C.

The specimen chamber has already been used with success in a fundamental investigation of the crystallographic transformations occurring in indium rich solid solution with thallium and lead$^{(11)}$ and currently in a systematic study of order-disorder transformations in the magnesium–cadmium system.

ACKNOWLEDGEMENTS

The work was initiated under the general directorship of the late Prof. D. Hanson and continued under Prof. G. V. Raynor and Prof. A. H. Cottrell whom we wish to thank for laboratory accommodation. We are particularly indebted to Mr. G. Elliott of the departmental workshop for help during construction of the chamber. Grateful acknowledgement is made of an Imperial Chemical Industries Research Fellowship (G. K. W.) and of a D.S.I.R. maintenance allowance (A. M.).

REFERENCES

(1) Williamson, G. K. *Bull. Inst. Metals*, **1**, p. 152 (1953).
(2) Peiser, H. S., Rooksby, H. P., and Wilson, A. . (Eds.). *X-ray Diffraction by Polycrystalline Mate* Chapter 7 (London: The Institute of Physics, 195
(3) Klug, H. P.; and Alexander, L. E. *X-ray Diffra Procedures* (New York: J. Wiley and Sons, 1955)
(4) Binks, L. S., and Friedman, M. *Rev. Sci. Instrum* p. 576 (1947).
(5) van Valkenburg, A., and McMurdie, H. F. *A Ceram. Soc. Bull.*, **26**, p. 139 (1947).
(6) Heal, H. T., and Nykura, N. *Met. Treatment* p. 129 (1950).
(7) Keating, D. T., and Warren, B. E. *J. Appl. Phys.* p. 286 (1951).
(8) Berry, R. L., Henry, W. G., and Raynor, G *J. Inst. Metals*, **78**, p. 643 (1951).
(9) Moore, A. *Ph.D. Thesis*, University of Birmingh 1955.
(10) Fink, W. L., and Willey, L. A. *Trans Amer. Min. Metall. Engrs*, **122**, p. 231 (1936).
(11) Moore, A., Graham, J., Williamson, G. K., Raynor, G. V. *Acta. Met.*, **3**, p. 579 (1955).

A continuous-flow rotational viscometer for use with downwar settling suspensions

By G. F. Eveson, B.Sc., Ph.D., and E. W. Hall, B.Sc., Grad.Inst.P., Mining Dept., University of Birmingha

[*Paper first received* 21 *September, and in final form* 4 *November*, 1955]

A rotational viscometer is described capable of measuring the apparent viscosity of downward-settling suspensions of particles sized below 100 B.S. mesh, where the settling velocity of the particles relative to the dispersion medium is less than 0·2 cm/s.

An interesting aspect of the study of the rheological properties of suspensions is the investigation of factors affecting the apparent viscosity of unstable suspensions. The main difficulty in such work is to find a suitable viscometer. Hitherto, it has not been possible to use a Couette-type instrument owing to the fact that particles settling out of an unstable suspension form a layer on top of the suspended inner cylinder or on the base of the outer cylinder; in either case, the end-effect for the inner cylinder is altered continuously and adequate correction cannot be applied. De Bruijn and Meerman$^{(1)}$ and Van der Walt and Fourie$^{(2)}$ have used modified Stormer viscometers for unstable suspensions, but de Bruijn and Meerman concluded that their viscometer was suitable only for those systems in which the energy required for homogenizing the suspension was negligible compared with the total work performed by the stirrer. Rising- and falling-sphere viscometers, in their present form, are not suitable for use with unstable suspensions. Oliver$^{(3)}$ used successfully an efflux-type capillary-tube viscometer with stable and both upward- and downward-settling suspensions and his results showed that the relationship between relative viscosity and solids concentration for the three types of suspension were markedly different. However, it is not possible to ascertain if the relative viscosity-solids concentration relationships observed for the unstable suspensions were influenced appreciably by characteristics peculiar to the type of viscometer used in the investigation. Until other methods for the measurement of the apparent viscosity of unstable suspensions have been evolved, little can be c to resolve this uncertainty. In this paper is describe rotational viscometer suitable for use with certain type unstable suspensions.

THEORETICAL CONSIDERATIONS

If a regular cylinder, suspended by a torsion wire thro its axis of symmetry, is immersed in a pure liquid contai in a concentric, cylindrically-shaped vessel which is cau to rotate at a constant speed, it is acted upon by the visc drag exerted by the liquid and can only be maintained i state of rest by means of a balancing couple exerted by torsion wire. By equating the applied torque to the mom of the viscous drag, an expression for the viscosity of liquid is obtained.

This principle has been employed successfully by a num of workers$^{(4,5,6)}$ to measure the apparent viscosity of st suspensions. These investigators assumed that a st suspension behaved similarly to a pure liquid in that particles moved with the dispersion medium in layers c centric with the axis of the viscometer, so that there was migration of particles towards either the inner or the o cylinder.

If a Couette-type viscometer is used for the measurem of the apparent viscosity of an unstable suspension, i necessary to prevent particles from settling out within viscometer, so that a homogeneous suspension is alw ent. This may be achieved by having a continuous flow he suspension through the instrument such that the city of flow of suspension down the annular gap between cylinders is greater than the settling velocity of the solid se relative to the dispersion medium. Any vertical ion of the suspension within the viscometer should not lidate the theory underlying the use of a rotational ometer but any radial motion of particles or liquid must voided.

viscometer embodying these principles was designed use primarily with downward-settling suspensions of icles smaller than 100 B.S. mesh, and where the settling city of the particles relative to the dispersion medium less than 0·20 cm/s.

DESCRIPTION OF THE APPARATUS

he viscometer (Fig. 1) is constructed of Perspex and sists of four separate parts; the head *A*, the outer nder *B*, the inner cylinder *C*, and a guard ring *D*. The d and the guard ring are sealed together and the unit so ned is a push fit on to the outer cylinder.

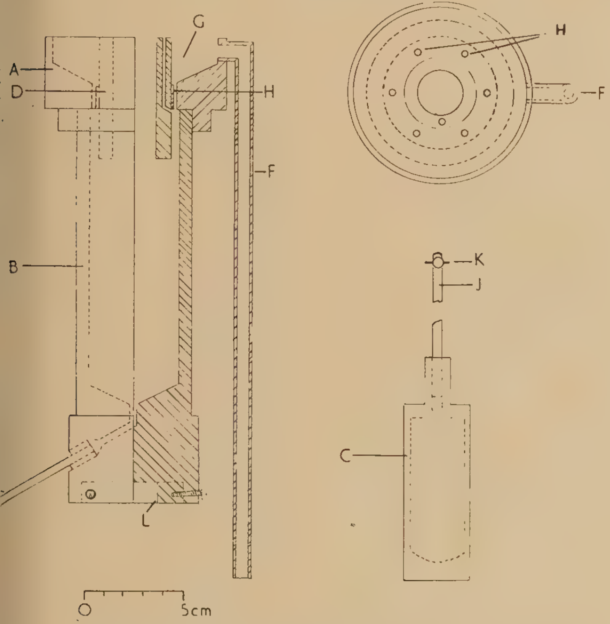


Fig. 1. Diagram showing the components of the continuous-flow rotational viscometer

1, head of viscometer; *B*, outer cylinder; *C*, inner cylinder;), guard ring; *E*, efflux tube of variable diameter; *F*, overflow ube; *G*, reservoir maintaining a constant head of fluid; *I*, holes of $\frac{1}{16}$ in. diameter; *J*, metal spindle; *K*, mirror; *L*, tapered brass collar.

The head contains a reservoir with an inclined base and ing a volume of approximately 80 ml. At the bottom of reservoir are six $\frac{1}{16}$ in. diameter holes, drilled vertically l equispaced around the circumference. The head has overflow, situated 0·59 in. above the base of the reservoir, ensure that there is a constant head of fluid to produce a ady rate of flow through the viscometer. Suspension leaves the outer cylinder (1·74 in. diameter) ough a $\frac{1}{8}$ in. diameter efflux tube leading from a conically-ped section. The rate of efflux of suspension is controlled means of the diameter of this efflux tube. Inset into the e of the outer cylinder is a tapered brass collar; this fits over the viscometer turntable which is in the form of a frustum of a cone.

The hollow inner cylinder (1·42 in. diameter) is loaded with sufficient mercury to give it a density slightly greater than that of the suspension flowing through the viscometer. This ensures that the phosphor-bronze torsion wire used for suspending the inner cylinder is subjected to a minimum tensile stress and keeps the centre of gravity of the inner cylinder as low as possible. This is desirable for coaxial alinement of the inner and outer cylinders. A thin brass spindle fits into the top of the inner cylinder; an 0·015 in. diameter vertical hole drilled centrally in the top of the spindle communicates with a 3/32 in. diameter horizontal hole about $\frac{1}{8}$ in. from the top of the spindle. The inner cylinder is suspended by a torsion wire anchored at the torsion head of the viscometer and in the 0·015 in. diameter hole in the brass spindle. The spindle also carries a small mirror which is used in conjunction with a lamp and scale to measure deflexions of the inner cylinder. The end effect for the base of the inner cylinder is made small by maintaining a large gap between the bases of the inner and outer cylinders.

A guard ring having an outer diameter equal to that of the inner cylinder is incorporated in the head of the viscometer. The gap between the guard ring and the top of the inner cylinder can be altered by means of a fine-adjustment screw on the torsion head carrying the torsion wire. The guard ring reduces end effects at the top of the inner cylinder, it prevents particles of the suspension settling on top of the inner cylinder and it allows the suspension entering the annular gap from the reservoir to reach a steady state of flow before passing vertically into the region between the inner and outer cylinders. A $\frac{1}{8}$ in. diameter hole in the wall of the guard ring leads from the atmosphere to the interior of the viscometer just below the reservoir. When the viscometer is filled with the fluid under test, no air is trapped inside the instrument and the fluid rises up inside the guard ring to the level of the overflow in the reservoir.

Fig. 2 shows the general arrangement of the viscometer and its ancillary equipment. The viscometer turntable is driven from an a.c. synchronous motor through interchangeable pulleys of various diameters and a fixed 225 : 1 gear reduction. The maximum rate of rotation of the outer cylinder is 0·15 rad/s which with the dimensions of the inner and outer cylinders of this viscometer, gives a maximum rate of shear at the wall of the inner cylinder of $0{\cdot}9\ s^{-1}$.

Fluid leaving the viscometer enters a trough in the form of an annular ring surrounding the base of the viscometer. The trough is inclined and at the lowest point is an offtake leading to the suction side of a diaphragm pump. The pump is driven from a 1/30 h.p. motor through a gear reduction unit and achieves two pulsations per second, delivery 5·0 ml./s of fluid against a head of about 30 in. A positive head of 4 in. is applied to the suction side of the pump. It is essential that the pump should not draw in air from the atmosphere or a suspension, which is a two-component system, will become a three-component system owing to the presence of finely-divided air bubbles.

The rate of delivery of the pump is such that there is a continuous overflow of fluid from the reservoir into the trough at the base of the viscometer. It was found that if the pulsating delivery of fluid from the pump were introduced directly into the reservoir, fluid passing from the reservoir into the viscometer also pulsed and made it impossible for a steady deflexion of the inner cylinder to be observed. A satisfactory solution to the problem is to deliver the fluid from the pump into a filter funnel which is connected by a short length of rubber tubing to a stirrup-shaped piece of glass tubing. The two ends of this tubing protrude into the reservoir to just below the level of the overflow and are arranged to be on a diameter of the viscometer head, so that the fluid is delivered in equal proportions symmetrically on either side of the vertical axis of the viscometer. A screw clip is placed on the rubber tubing connecting the filter funnel to the glass stirrup and is adjusted so that there is always some fluid remaining in the funnel. The pulsations in the delivery of fluid from the pump are smoothed out in the filter funnel, from which fluid flows at a steady rate to the reservoir in the viscometer head.

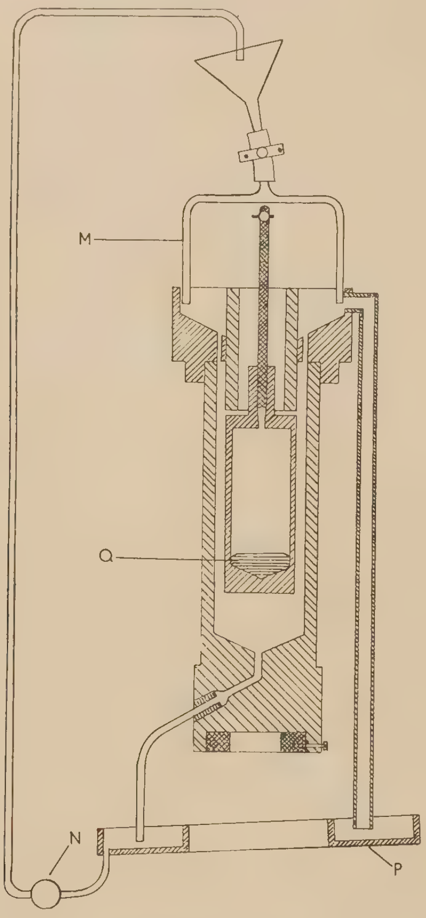


Fig. 2. General arrangement of the viscometer and ancillary equipment

M, delivery tubes; *N*, diaphragm pump; *P*, inclined trough; *Q*, mercury.

Suspensions of spherical Kallodoc particles in various polar media have been used in the viscometer. These particles, which are made of a methyl methacrylate polymer, were examined microscopically after they had been pumped round the apparatus for various lengths of time up to half an hour, and no evidence was found of distortion of the particles having occurred. Kallodoc (by I.C.I. Ltd.) is a relatively soft material so it appears likely that a diaphragm pump will handle safely particles which would be abraded in a centrifugal-type of pump.

EXPERIMENTAL

It was necessary to show experimentally that the theor considerations underlying the use of the conventional tional viscometer are applicable to this continuous rotational instrument. An aqueous glycerol solution placed in the outer cylinder with the outlet closed. deflexion of the inner cylinder was observed for various of rotation of the outer cylinder. The aqueous gly solution was then circulated through the viscomete various rates of flow and the deflexion of the inner cyli observed at the same rates of rotation of the outer cyli as were used with the outlet closed. The following contains readings obtained with the outer cylinder rot at 0·031 rad/s, and are typical of the values obtained o range of outer cylinder speeds.

Variation of mean deflexion with rate of flow of solutio

Rate of flow of solution through viscometer (ml./min)	*Mean deflexion of inner cylin measured on scale (cm)*
0	7·50
21·5	7·50
29·0	7·60
35·0	7·45
54·0	7·70
68·0	No steady reading.

When using downward-settling suspensions of 200–30 mesh spherical particles it was also found that the defle measured with the viscometer outlet closed was the sa the deflexions measured with rates of efflux below a 65 ml./min. The exact significance of this critical rat efflux is not known. It corresponds to a velocity of flo the suspension through each of the $\frac{1}{16}$ in diameter hole 9·0 cm/s and down the annular space, between the i and outer cylinders, of 0·22 cm/s. Such flow is well wi the laminar flow region.

When suspensions are pumped round the system, equilibrium concentration of solids is reached after tw three minutes and this concentration is maintained cons for at least thirty-five minutes, which is the maximum t for which any one suspension has as yet been observed.

It is considered that after calibrating the viscometer pure liquids of known viscosity, it can be used satisfact to determine the apparent viscosity of downward sett suspensions within the limitations mentioned in this pape

REFERENCES

(1) De Bruijn, H., and Meerman, P. G. *Proceedings of International Rheological Congress, Holland, Part* p. 160 (Amsterdam: North Holland Publishing 1948).

(2) Van der Walt, P. J., and Fourie, A. H. *J. S. Afr Chem. Inst.*, **7**, p. 61, No. 2 (1954).

(3) Oliver, D. R. *Ph.D. Thesis*, University of Birmingh (1954).

(4) Vand, V. *J. Phys. Coll. Chem.*, **52**, p. 277 (1948).

(5) Eveson, G. F. *Ph.D. Thesis*, University of Birmingh (1950).

(6) Sweeny, K. H., and Geckler, R. D. *J. Appl. Phys.*, p. 1135 (1954).

A simple fast-recycling cloud chamber

J. Walker, Ph.D., F.Inst.P., G. Tagliaferri, D. in F.,* J. C. Bower, Ph.D., F.Inst.P.,† and D. W. Hadley, B.Sc.,
Department of Physics, University of Birmingham

[*Paper first received* 12 *September, and in final form* 21 *November*, 1955]

A simple modification to a standard 9 in. diameter expansion chamber is described which decreases the operating cycle from 60 s to 10 s. Over-compression is used and the results obtained for different operating conditions throw some light on the mechanism of the process.

of the disadvantages of the expansion cloud-chamber is long re-setting time which results in inefficient operation; e reliable method of reducing this would be of consider- value. Re-setting times of a minute or longer are typical chambers working at about atmospheric pressure, whereas sensitive time is, at most, a few tenths of a second. The ll chamber made by Brinkman(1) had a very short re- ng time of less than one second, but its application is ted by its shallow sensitive volume. More useful mbers have been described by Gaerttner and Yeater(2) Emigh,(3) both based on the idea of re-compressing kly after the expansion. Gaerttner and Yeater developed over-compression method in which the gas is compressed dly after expansion to a pressure above the pre-expansion and then returned fairly slowly to the initial setting. igh simply re-compressed the gas to its pre-expansion ssure very rapidly ("fast-recompression"). Although no her paper has been published on over-compression nique since that of Gaerttner and Yeater, some additional k was reviewed by Barford at a recent conference.(4)

he diffusion cloud-chamber(5) offers an alternative method achieving efficient operation and its simplicity makes it very attractive instrument for use with high-energy elerators. However, its limited sensitive depth and riction to horizontal working considerably reduce its ie for cosmic-ray work, and even for machine applications iculties arise when internal metal plates are used. In view his, the authors decided to apply over-compression to an sting expansion chamber in an attempt to synchronize ansions with the pulses from the Birmingham proton chrotron which recur every ten seconds. The modified mber has been used both with and without metal plates l has given satisfactory tracks for successive synchrotron ses.

ARRANGEMENT OF CHAMBER

he chamber is 9 in. in diameter and 2 in. deep and is rated horizontally. The base of the sensitive region is med, as usual, by a perforated brass plate which before modification acted as the upper stop for the rubber phragm. The lower stop in the original arrangement was econd perforated plate which could be moved up and wn to provide adjustment of the expansion ratio.

his system can clearly be arranged to work as an over- npression chamber if the rubber diaphragm is held initially a position between the two stops; expansion and over- npression can then be obtained by forcing the diaphragm or down from its initial position. This has been done by efully controlling the pressure of air behind the diaphragm set the pre-expansion position and then connecting the k-space to a higher pressure for a short time after the ansion. Pfotzer(6) has shown that this way of controlling expansion ratio is likely to need better temperature stability than the method of working between fixed stops, but the authors have not experienced trouble in spite of having no temperature stabilization beyond passing tap water through a coil on the base of the chamber. The arrangement of the control system is shown in Fig. 1. Compressed air is fed into reservoir R_1 through the simple pressure control valve, shown in the inset, which is used to eliminate the effect of large pressure fluctuations in the supply line. Reservoir R_2 is used for the pneumatic control and has its pressure controlled at the appropriate pre-expansion value to better than 2 mm of mercury relative to the atmosphere by the combination of a double contact manometer and the two solenoid valves V_3, V_4. One of the manometer arms is drawn to a fine bore over a short length to provide damping and prevent oscillation in the control system. Adjustment of the pre-expansion pressure and hence of the expansion ratio is given by movement of contacts C_1 and C_2. Expansion is effected by opening valve V_1, which is closed again within some 200 ms, and the over-compression valve V_2 is then opened for a short time so that the pressure in the back-space is raised rapidly to that maintained in R_1, thus forcing the diaphragm upwards. The amount of over-compression depends on the pressure at which R_1 is regulated.

Carefully washed rayon velvet is used on the base of the chamber; the excellent optical properties of this are well known and in addition, as distinct from velveteen, this material does not constitute a source of condensation nuclei.

Satisfactory tracks have been obtained with three different diaphragms: $\frac{1}{8}$ in. rubber, $\frac{1}{16}$ in. rubber and $\frac{1}{16}$ in. Bakelite sheet embedded in rubber to give a uniform sheet $\frac{1}{8}$ in. thick. The Bakelite was 2 in. less in diameter than the whole diaphragm and thus gave a rubber annulus wide enough to allow freedom of motion without undue distortion. This reinforced diaphragm leads to less gas motion, particularly when used with an air exit placed centrally below it; the tracks in Fig. 2 were photographed with this arrangement.

OPERATING CONDITIONS

Without over-compression this chamber required about 60 s resetting time in order to obtain consistently good tracks, but with over-compression this time has been reduced to 10 s. As this is the repetition time of the Birmingham synchrotron no attempt has been made to get still shorter times. Under typical conditions the chamber gas was argon with ethyl alcohol and water (2 : 1) as the condensible vapour; with an initial pressure of 93·0 cm of mercury, the optimum expansion ratio was 1·10 with 1·12 for the over-compression ratio (pressure at over-compression/initial pressure). The chamber remained expanded for 0·3 s and over-compressed for 0·5 s; the return to normal pressure took 3·5 s. A clearing field of 70 V/cm was applied at all times except during expansion.

Expansion and over-compression ratios were measured with a mercury manometer calibrated for transient readings

---

* Now at Princeton University, New Jersey, U.S.A.

† Now at University of Melbourne, Australia.

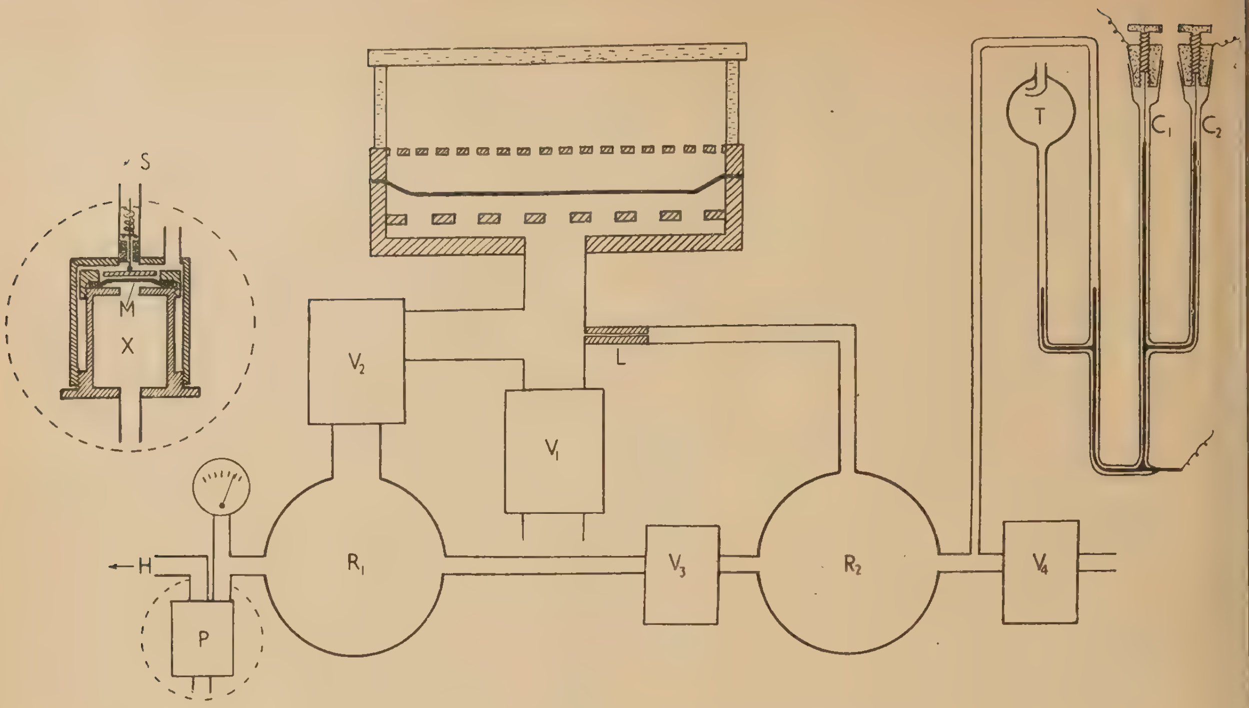


Fig. 1. Control system for over-compression chamber

R_1, *R_2*, tanks containing compressed air; *V_1*, expansion valve; *V_2*, over-compression valve; *V_3*, *V_4*, valves controlling pre-expansi pressure; *C_1*, *C_2*, manometer contacts (platinum–mercury) controlling *V_3*, *V_4*; *T*, trap for mercury when pressure rises abnorma *H*, laboratory high pressure line; *L*, slow leak; *P*, pressure control unit, shown in detail in inset; *X*, reference volume pressure control unit; *M*, thin rubber membrane; *S*, Schrader valve.

against a capacitance type pressure gauge (part of an engine indicator, type ME122, made by Southern Instruments Co. Ltd.) which was fitted to the chamber wall.

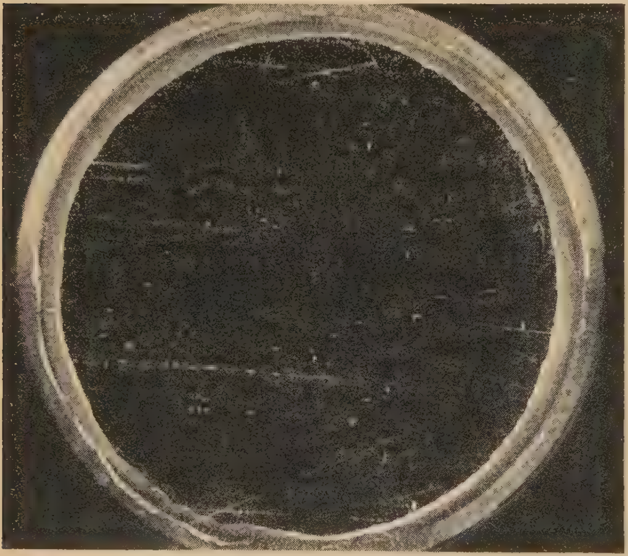


Fig. 2. Tracks of 650 MeV protons

VARIATION OF EXPANSION RATIO WITH AMOUNT OF OVER-COMPRESSION

Repeated observations have shown that the expansion ratio which gives best quality tracks decreases slightly with increase
in the over-compression ratio for a fixed repetition per
and also decreases as the repetition period is reduced f
fixed over-compression. In a typical set of observations
optimum expansion ratio decreased from 1·11 to 1·09 as
over-compression ratio was increased from 1·05 to
and the expansion ratio fell from 1·09 to 1·08 as
repetition period was reduced from 15 to 10 s. These res
can be explained if the expansion and over-compression c
produces a net cooling of the chamber gas. With the o
compressed state lasting longer than the expanded state
in this arrangement, a cooling will indeed be expected, si
the fall in temperature while the gas is over-compressed,
therefore hotter than its surroundings, will be greater t
the rise while it is expanded. Barford⁽⁴⁾ has already poin
out that it may be possible to make the rise equal to the
so that there is no net change in temperature over the cy
In fast re-compression, on the other hand, each cycle m
produce a net heating and one should therefore have
increase the expansion ratio in order to maintain tr
quality when an over-compression cycle was altered to a
re-compression cycle. With the present control system
alteration can be made very simply by connecting the
reservoirs together directly instead of through the valve
When the chamber was operating on an over-compress
cycle with ambient conditions such that the optim
expansion ratio was 1·08, the change to re-compress
working called for a change in expansion ratio to 1·10
satisfactory track formation. The observed changes
expansion ratio are in agreement with those calculated
terms of the estimated temperature variation and availa
data on the change of expansion ratio with temperatu
This shows that the simple picture of temperature change
reasonable.

OMPARISON BETWEEN OVER-COMPRESSION AND FAST RE-COMPRESSION

r a chamber operating at irregular intervals there is no t that a balanced cycle of expansion and over-compres- with no net change in temperature will be advantageous igh rates. For regular operation the advantage will be narked because, for an unbalanced cycle, the temperature e start of each cycle will rapidly settle to a steady value e or below the ambient temperature and the expansion can be adjusted accordingly. It is interesting, therefore, mpare over-compression and fast re-compression with ar operation as any difference observed should be due uses other than net change in temperature over each . When making this direct comparison the authors d that the background cloud, with the expansion ratio sted for good track formation, was very much heavier fast-recompression than with over-compression. It is luded, therefore, that over-compression is a more satis- ry technique than fast re-compression, at least for a ure controlled chamber, and that the difference is ably due to the return from the over-compressed state g as a clearing expansion. A more efficient re- oration of droplets by over-compression could also in the difference, but some evidence against this has been by Barford, and the authors have also observed by a le flash technique the persistence of tracks after over- ression has been applied.

ACKNOWLEDGEMENTS

We are pleased to acknowledge the interest shown in this work by Profs. P. B. Moon and W. E. Burcham. We are grateful to the Dunlop Rubber Co. Ltd., Birmingham, for making the embedded Bakelite diaphragm and to the Mechanical Engineering Department of the University of Birmingham for the loan of the capacitance type pressure gauge.

One of us (G. T.) is grateful to Societa Italiana di Fisica and to the United Nations Educational, Scientific and Cultural Organization for research fellowships and another (D. W. H.) to the University of Birmingham for a research scholarship. G. T. took part in this work while on leave from the University of Milan and J. C. B. while on leave from the University of Melbourne.

REFERENCES

(1) Brinkman, H. *Physica*, **6**, p. 519 (1939).

(2) Gaerttner, E. R., and Yeater, M. L. *Rev. Sci. Instrum.*, **20**, p. 588 (1949).

(3) Emigh, C. R. *Rev. Sci. Instrum.*, **25**, p. 221 (1954).

(4) Burhop, E. H. *Nature* [*London*], **175**, p. 832 (1955); and private communication from N. C. Barford.

(5) Snowden, M. *Progr. Nucl. Phys.*, **3**, p. 1 (1953).

(6) Pfotzer, G. *Rev. Sci. Instrum.*, **25**, p. 521 (1954).

A simple theory for solid-backed bolometers

By L. M. Roberts, M.A., A.Inst.P., and S. J. Fray, Radar Research Establishment, Great Malvern, Worcs.

[*Paper received* 9 *November*, 1955]

A simple theory is proposed to explain the frequency response of solid-backed bolometers. It assumes a one-dimensional flow of heat through the bolometer and takes into account the diffusivity of the adhesive used for sticking the bolometer element to its base. The theory has been applied to measurements on some niobium nitride superconducting bolometers and the results are in good agreement with the known properties of the materials used.

INTRODUCTION

work described in this paper formed part of some rimental investigations(1) into the use of niobium nitride rconducting bolometers as radiation detectors, and a outline of the construction and use of the bolometers serve as an introduction.

ich bolometer consisted of a thin strip of niobium nitride to a copper or artificial sapphire base. In operation ase was maintained at a constant temperature such that itride was in the middle of the superconducting transition nd 16° K. In this condition a very small change in the perature of the nitride, such as that produced by incident ation, was accompanied by a comparatively large change ectrical resistance which was a sensitive measure of the unt of radiation received. The changes of resistance observed by passing a constant direct current through itride and measuring the voltage across it.

e way in which the nitride was mounted on its base rmined the thermal characteristics of the bolometer and e its sensitivity and speed of response. Two different ods were used: a "vacuum" mounting, in which the nitride strip was supported only at its ends, and a "solid-back" mounting, in which the whole length of the nitride was stuck to the base with an insulating adhesive. Measurements on the "vacuum" type gave results which could be interpreted on the commonly-used simple model, in which the bolometer is represented as a heat capacity connected by a thermal resistance to a constant temperature sink.(2) The frequency responses of the solid-backed type were, however, inconsistent with this model. For that reason the theory discussed in this paper was developed; it takes account of the heat capacity of the insulating varnish as well as that of the nitride and gives very plausible quantitative agreement with experiment. The simpler theory referred to above appears as a limiting case.

THEORY

The model used is shown in Fig. 1, where P represents the bolometer element, Q the insulating varnish and S the base or thermal sink. A constant measuring current i is passed through the element P and the radiation incident upon it at any moment is W.

The following simplifying assumptions are made: that the heat flow is one dimensional and in a direction perpendicular to the receiving face of the element, that the element has a high thermal conductivity so that its temperature is always uniform and equal to that of the adjoining face of insulator Q, and that the temperature of S is constant. The incoming radiation will be assumed sinusoidal, having the form $W = W_0[\exp(j\omega t) + 1]$, where W_0 is a constant and ω is an angular frequency.

Let c be the specific heat per unit volume of Q, g the specific thermal conductivity of Q, $n = g/c$ the diffusivity of Q, γ the total heat capacity of P, R the electrical resistance of P at any instant, a the area of the receiving face, and l the thickness of Q.

Now consider a lamina of Q distant x from S and of thickness δx. Let the temperature at x be T and at $x + \delta x$ be $T + \delta T$. Then the heat balance equation for the lamina is

$$g\frac{\partial^2 T}{\partial x^2} = c\frac{\partial T}{\partial t}$$

that is

$$n\frac{\partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t}$$

The required solution of this equation is

$$T = \exp(qt)\left\{A\exp\left[(q/n)^{\frac{1}{2}}x\right] + B\exp\left[-(q/n)^{\frac{1}{2}}x\right]\right\} + Dx + E$$

where A, B, D, E and q are to be determined.

Let the sink temperature be taken as zero, then one boundary condition is

$$T = 0 \quad \text{at} \quad x = 0 \quad \text{for all } t$$

At the opposite face of Q the incoming radiation plus the electrical heat dissipated in P is balanced by the quantity of heat used to alter the temperature of P and the rate at which heat is conducted away through Q. Hence the boundary condition is

$$W + i^2R = \gamma(dT/dt) + ga(dT/dx) \quad \text{at} \quad x = l \quad \text{for all } t$$

In addition it is convenient to assume that over the small range of temperatures used R is linear with temperature, so that R can be written in the form $[R_0 + T(dR/d\theta)]$, where R_0 and $dR/d\theta$ are both constant, θ being the absolute temperature of P.

Inserting the boundary conditions gives $q = j\omega$, $E = 0$ and

$$A = -B = W_0\left(ga\left(\frac{q}{n}\right)^{\frac{1}{2}}\left\{\exp\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right] + \exp\left[-\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right]\right\} + \left(\gamma q - i^2\frac{dR}{d\theta}\right)\left\{\exp\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right] - \exp\left[-\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right]\right\}\right)^{-1}$$

$$D = (i^2R_0 + W_0)\Big/ga\left(1 - \frac{i^2}{ga}\cdot\frac{dR}{d\theta}l\right)$$

Hence

$$T = \frac{\left\{\exp\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}x\right] - \exp\left[-\left(\frac{q}{n}\right)^{\frac{1}{2}}x\right]\right\}W_0\exp(j\omega t)}{ga\left(\frac{q}{n}\right)^{\frac{1}{2}}\left\{\exp\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right] + \exp\left[-\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right]\right\} + \left(\gamma q - i^2\frac{dR}{d\theta}\right)\left\{\exp\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right] - \exp\left[-\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right]\right\}} + \frac{(i^2R_0 + W_0)x}{ga\left(1 - \frac{i^2}{ga}\frac{dR}{d\theta}l\right)}$$

The temperature θ' of P, referred to that of the si
zero, is obtained by inserting $T = \theta'$ and $x = l$ in equatio
thus

$$\theta' = \frac{W_0\exp(j\omega t)\tanh\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right]}{ga\left(\frac{q}{n}\right)^{\frac{1}{2}} + \left(\gamma q - i^2\frac{dR}{d\theta}\right)\tanh\left[\left(\frac{q}{n}\right)^{\frac{1}{2}}l\right]} + \frac{(i^2R_0 +}{ga\left(1 - \frac{i^2}{ga}\right.}$$

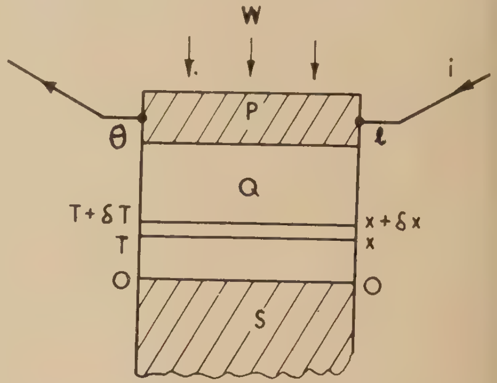


Fig. 1. Schematic diagram of bolometer

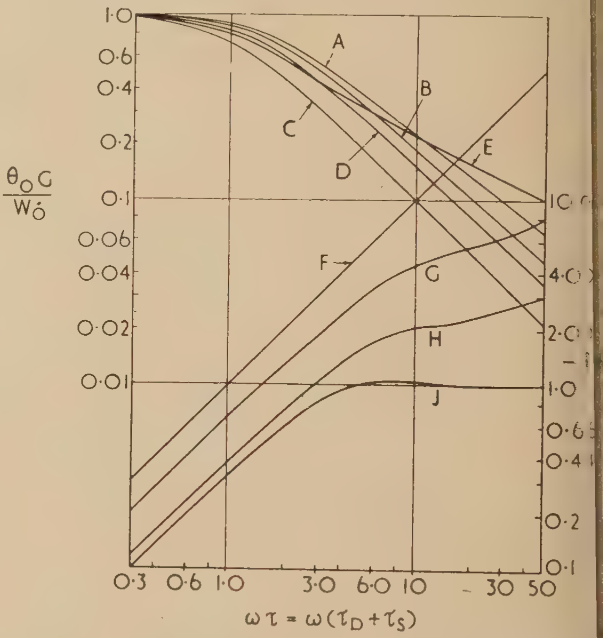


Fig. 2. Theoretical curves of response and phase an
as functions of frequency

Curve A, θ_0G/W_0 $(\gamma/C = 0{\cdot}25)$; curve B, θ_0G/W_0 $(\gamma/C = 0\cdot$
curve C, θ_0G/W_0 $(\gamma/C = \infty)$; curve D, θ_0G/W_0 $(\gamma/C =$
curve E, θ_0G/W_0 $(\gamma/C = 0)$; curve F, $-\tan\phi$ $(\gamma/C =$
curve G, $-\tan\phi$ $(\gamma/C = 1)$; curve H, $-\tan\phi$ $(\gamma/C = 0{\cdot}2$
curve J, $-\tan\phi$ $(\gamma/C = 0)$.

Now put $C = cla$ = the total thermal capacity c
$G = ga/l$ = the thermal conductance of Q, $\tau_D = C/$
$cl^2/g = l^2/n$, and $\tau_S = \gamma/G$.

en

$$\frac{W_0 \exp (j\omega t) \tanh (j\omega\tau_D)^{\frac{1}{2}}}{G\left[(j\omega\tau_D)^{\frac{1}{2}} + \left(j\omega\tau_S - \frac{i^2}{G}\frac{dR}{d\theta}\right)\tanh (j\omega\tau_D)^{\frac{1}{2}}\right]} + \frac{i^2R_0 + W_0}{G\left(1 - \frac{i^2}{G}\frac{dR}{d\theta}\right)}$$

serting the dimensionless variables

$$= \frac{i^2}{G}\frac{dR}{d\theta}, \quad \alpha = \left(\frac{\omega\tau_D}{2}\right)^{\frac{1}{2}}, \quad \text{i.e. } (j\omega\tau_D)^{\frac{1}{2}} = (1+j)\alpha,$$

$$\beta = \omega\tau_S$$

$$\frac{W_0 \exp (j\omega t) \tanh [(1+j)\alpha]}{G\{(1+j)\alpha + (j\beta - b)\tanh [(1+j)\alpha]\}} + \frac{i^2R_0 + W_0}{G\left(1 - \frac{i^2}{G}\frac{dR}{d\theta}\right)}$$

ere the second term gives the mean rise in temperature , while the first term is the oscillatory component of perature, which is the one usually observed in practice. fter rationalizing, this oscillatory term may be rewritten e form

$$\theta' = \theta_0 \exp [j(\omega t + \phi)]$$

re

$${}_0 = \frac{W_0}{G}\left[\frac{\tan^2\alpha + \tanh^2\alpha}{2\alpha^2(1 + \tan^2\alpha\tanh^2\alpha) - 2\alpha(\beta + b)\tan\alpha\,\mathrm{sech}^2\alpha + 2\alpha(\beta - b)\tanh\alpha\sec^2\alpha + (\beta^2 + b^2)(\tan^2\alpha + \tanh^2\alpha)}\right]^{\frac{1}{2}} \qquad (2)$$

$$\tan\phi = \frac{\tan\alpha\,\mathrm{sech}^2\alpha - \tanh\alpha\sec^2\alpha - (\beta/\alpha)(\tan^2\alpha + \tanh^2\alpha)}{\tan\alpha\,\mathrm{sech}^2\alpha + \tanh\alpha\sec^2\alpha - (b/\alpha)(\tan^2\alpha + \tanh^2\alpha)} \qquad (3)$$

he corresponding voltage oscillations are now easily ved, for evidently

$$V = i\frac{dR}{d\theta}\theta'$$

the oscillatory component may be written as

$$V = V_0 \exp [j(\omega t + \phi)] = i\frac{dR}{d\theta}.\theta_0 \exp [j(\omega t + \phi)]$$

he responsivity r of the bolometer, defined as V_0/W_0, is refore given by

$$r = i\frac{dR}{d\theta}\cdot\frac{\theta_0}{W_0} \qquad (4)$$

ne variation of r with frequency is the same as the variation θ_0 and if suitable approximations are made in equations and (3), the following general points emerge.

t very low frequencies ($\omega\tau_D$ and $\omega\tau_S \ll 1$, i.e. α and β to zero) equations (2) and (3) become

$$\theta_0 = \frac{W_0}{G(1-b)} \quad \text{and} \quad \tan\phi = 0$$

s at low frequencies θ_0 is independent of frequency and he heat capacities γ and C, and there is no phase difference ween the input radiation signal and the output voltage. wever, as the measuring current is increased so that $(i^2dR/d\theta)/G$ tends to 1, θ_0 tends to infinity. For a erconducting bolometer this means, in practice, that the em becomes unstable and it is impossible to keep the perature of the element in the transition range. The imum measuring current which can be used is therefore limited. The physical interpretation has been discussed by Andrews.(3) For other types of bolometer this situation does not necessarily occur, e.g. when $dR/d\theta$ is negative as in a semiconducting bolometer.

At higher frequencies the slope of the curve depends on the relative values of γ and C, that is τ_S and τ_D. When $\gamma \gg C$ the equations reduce to those obtained from the simpler theory mentioned in the introduction, namely,

$$\theta_0 = \frac{W_0}{G[(1-b)^2 + \omega^2\tau_S^2]^{\frac{1}{2}}} \quad \text{and} \quad \tan\phi = -\frac{\omega\tau_S}{1-b}$$

so that at high frequencies ($\omega\tau_S \gg 1$) the amplitude of the temperature oscillations becomes proportional to ω^{-1} and independent of the measuring current. (The responsivity is then directly proportional to the current, although the maximum current which can be used is still limited by the instability condition.)

When $C \gg \gamma$ equations (2) and (3) do not reduce to a very simple form for all frequencies, but it is not difficult to show that at moderately high frequencies when $\omega\tau_D \gg 1$ but $\omega\tau_S$ is still small, θ_0 becomes proportional to $\omega^{-\frac{1}{2}}$ and once again the expressions become independent of current. At very high frequencies [$\beta \gg \alpha$, i.e. $\omega\tau_S \gg (\omega\tau_D)^{\frac{1}{2}}$] θ_0 becomes proportional to ω^{-1} as above, but at such frequencies the responsivity has usually fallen too low to be of practical interest.

The variations of the response with frequency are shown for a number of values of $\gamma/C(=\tau_S/\tau_D)$ in Fig. 2, where $\log (\theta_0G/W_0)$ is plotted against $\log \omega(\tau_S + \tau_D)$. The measuring current has been assumed small, that is, terms containing b have been neglected. Including them simply has the effect of increasing the low frequency values. The variation in the high frequency slopes with γ/C should be observed. Curves of $\tan\phi$ are also given in Fig. 2.

EXPERIMENTAL DETAILS

The cryostat used to keep the niobium nitride element in its superconducting transition, around 16° K, was similar to that described by Fuson.(4) The bolometer base was soldered with Wood's metal to a copper rod connected to a liquid hydrogen container and the correct temperature was maintained by controlling the vapour pressure over the hydrogen and hence the temperature at which the liquid boiled. In this way the temperature of the base could be kept constant to about 1/500° K. Radiation was admitted to the cryostat through a thallium bromo-iodide (KRS5) window. Measurements of responsivity were made using a blackbody at about 400° K, the radiation from which was chopped almost sinusoidally at 800 c/s. The resulting voltage was amplified at 800 c/s in a 31 c/s bandwidth and was displayed on an oscilloscope and measured on a thermal millivolt meter. For frequency response measurements the source of radiation was a tungsten filament lamp; a wide-band amplifier was used and variable speed choppers covered a frequency range from 15 to 1500 c/s.

To obtain d.c. resistance temperature curves, and hence a value for $dR/d\theta$, the bolometer was screened from the incident radiation and the temperature of the base was varied by varying the pressure over the liquid hydrogen. The same measuring current was used as for the responsivity measurements and the voltage across the nitride was measured on a d.c. potentiometer. The temperature of the base was measured with a previously calibrated constantan resistance thermometer wound either on the base itself or on the copper rod to which it was soldered.

The niobium nitride for the bolometers was made from niobium metal supplied (by Johnson, Matthey and Co. Ltd.) in the form of wire, ribbon or rod, and rolled in the laboratory into suitable strips, 2 to 4 cm long, 0·5 to 2·0 mm wide and about 0·0025 cm thick. Each strip was suspended in a constantly changing atmosphere of pure dry ammonia and was kept at a temperature of 1400° C for $\frac{3}{4}$ h by passing an electric current through the niobium. The ends of the resulting pieces of nitride were then copper plated and tinned ready for electrical connexions. For vacuum mounting a rod of artificial sapphire, stuck at one end into a copper former, was used as the base. Two strips of copper foil suitably spaced were stuck round the sapphire with Araldite, and the ends of the nitride were soldered one to each copper strip. Fine copper wires, one current and one voltage lead for each end, were then wound round the strips and soldered down. For a few bolometers the copper bands were not used; instead the holder was hollowed out beneath the element and the tinned ends were stuck directly to the sapphire with Araldite. Copper bases were initially tried but the brittle nitride invariably broke on cooling owing to the relatively large contraction of the copper; artificial sapphire has as high a thermal conductivity as copper at 16° K but a smaller expansion coefficient. For the solid-back mounting the nitride element with its ends already tinned was stuck to the base with a layer of varnish or Araldite. Artificial sapphire and varnish- or Araldite-insulated copper bases were both used. However, less experimental information was obtained on the varnish-mounted bolometers since the varnish proved to be less elastic than Araldite and the breakage rate on cooling was high. With the sapphire bases the copper bands used for vacuum mounting were sometimes retained; if so, they were cut away, so that the nitride lay flat on the base with the tinned ends in grooves in the copper.

RESULTS

Results for sixteen bolometers are summarized in the table. One bolometer was measured on three separate occasions denoted by (i), (ii) and (iii), and two others, 167*a* and 190*a*, were modified after test and remeasured as 167*b* and 190*b*.

The frequency responses were measured on an arbitrary scale and converted to absolute units by reference to the independently measured 800 c/s responsivity; they were then plotted in terms of $\log(\theta_0/W_0)$ against $\log f$. Curves for three bolometers are given in Fig. 3. The results were analysed by choosing the most suitable curve from Fig. 2 and fitting it to the measured frequency response. A value for G could then be obtained from the ordinate scale and a value for $\tau = \tau_S + \tau_D$ from the abcissa scale. The deviations at low frequencies from the theoretical curves (Fig. 3) are attributed to a compound time constant effect similar to that observed by Andrews.(3) The curve chosen for each bolometer is indicated in column 8 of the table and the deduced values of G (milliwatts/°K) and τ (milliseconds) are given in columns 9 and 10. Column 11 contains values of $C + \gamma$ ($=G\tau$) in erg/°K. Since the areas of the bolometers differ gr values of G/a and $(C + \gamma)/a$ are given in columns 12 ar for comparison.

In the table the bolometers are arranged in ord increasing values of G/a and in this way a marked relatio between the method of mounting and the results obtain the above analysis can be seen quite clearly. The firs

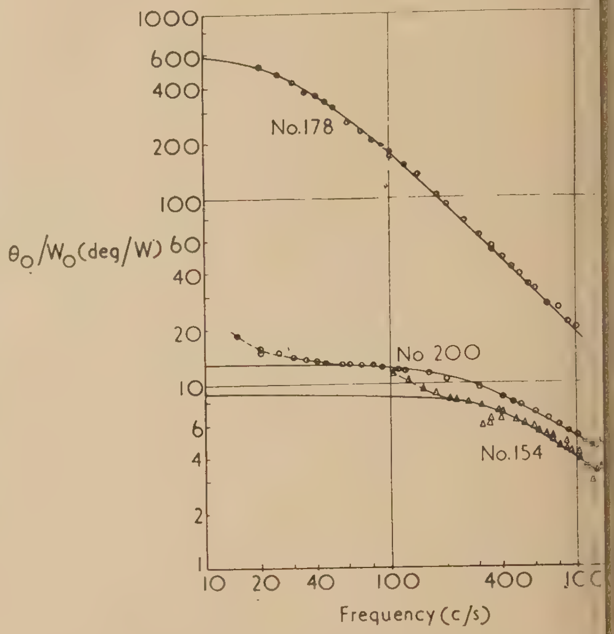


Fig. 3. Frequency response curves for bolomet Nos. 154, 178, 200

No. 154, theoretical curve for $\gamma/C = 0{\cdot}25$. $\tau = 0{\cdot}66$ m
No. 178, theoretical curve for $\gamma/C = \infty$. $\tau_S = 5{\cdot}5$ ms.
No. 200, theoretical curve for $\gamma/C = 0$. $\tau_D = 0{\cdot}56$ ms.

bolometers which have values of G/a averaging a 0·7 mW/(°K mm²) are all vacuum mounted with co band type contacts. All but one require $\gamma/C = \infty$ and heat capacities per unit area are low, between 15 40 erg/(°K mm²). The nitride itself, with a heat capaci about 16 erg/(°K mm²),(5) is therefore an appreciable po of the total. The remaining heat capacity is easily expla in terms of small quantities of copper plating or so oscillating in temperature with the nitride.

The last ten bolometers are all Araldite-mounted and values obtained for G/a are an order of magnitude or greater than those of the vacuum-mounted ones. All but require values of γ/C of 0·25 or zero and the value $(C + \gamma)/a$ vary between 50 and 850 erg/(°K mm²). Th consistent with the very good adhesive properties and heat capacity of Araldite. A layer of fully polyme Araldite 0·02 mm thick, which was the order of thick normally used, has a heat capacity of about 120 erg/(°K m at 16° K(6) in reasonably good agreement with the value column 13. In the sapphire-based bolometer a very layer of Araldite could safely be used since there was no for electrical insulation, and it may be seen that in ge the values of $(C + \gamma)/a$ are slightly lower for these b meters. The high heat capacity of 79 was caused by the of Araldite in stick form softened and smeared on the hol for the later bolometers a solution of Araldite powde acetone (1 g to 5 cm³) was employed.

Table of experimental results

meter iber	Mount*	Effective area† (mm²)	i (mA)	R (Ω)	dR/dT (Ω/°K)	V_0/W_0 (800 c/s) (mV/w)	Theory γ/C	G (mW/°K)	$\frac{C+\gamma}{G}$ (ms)	$C+\gamma$ (erg/°K)	G/a [mW /(°K mm²)]	$\frac{C+\gamma}{a}$ [erg /(°K mm²)]
0 b	SVb	5·55	2	0·30	0·40	20·4	∞	1·31	6·4	83·8	0·238	15·1
6	SVb	1·55	10	0·047	0·09	73·6	∞	0·386	6·7	25·85	0·249	16·7
0	SVb	1·37	10	0·33	0·054	45·3	0·5	1·26	3·54	44·6	0·92	32·6
7 b	SVb	1·95	10	0·28	0·053	20·2	∞	2·16	2·49	53·8	1·11	27·6
7 a	SVb	1·95	10	0·064	0·066	19·0	∞	2·18	3·5	76·4	1·12	39·1
8	CAV	1·16	10	0·03	0·08	19·0	∞	1·63	5·5	89·7	1·41	77·3
2	SB	7·7	10	0·065	0·095	7·1	∞	11·3	2·6	294	1·47	38·2
0 a	SV	5·55	10	0·155	2·98	96	∞	11·1	5·9	655	2·0	118
2	CB	—	17	—	—	—	1·0	—	1·15	—	—	—
4	SAb	6·0	10	2·87	2·51	195	No theoretical curve to fit experiment					—
1	SAb	3·24	50	0·342	1·88	930	0·25	23·8	1·94	462	7·35	143
6	SA	7·7	10	0·276	0·262	5·75	0·25	93	2·45	2280	12·05	296
0	SAb	6·67	10	0·56	3·42	194	0	79·9	0·56	446	12·0	66·9
8 ii	CA	5·1	10	0·2	1·65	31·4	1·0	68·8	2·49	1712	13·5	336
7	CA	5·5	10	0·2	0·41	29·2	0	82	0·35	287	14·9	52·2
9	CA	3·6	10	0·047	0·08	3·8	0	54·2	1·6	868	15·1	241
9	CA	2·6	5	0·07	2·1	31·7	0	47·5	4·61	2190	18·3	843
8 i	CA	5·1	10	0·2	1·6	37·6	0·25	136·5	1·33	1810	26·7	355
4	SA	4·1	10	0·235	0·278	12·6	0·25	115	0·66	759	28·1	185
8 iii	CA	5·1	10	0·27	1·68	33·4	0·25	154·5	1·38	2140	30·4	420

* C = copper. S = sapphire. A = Araldite. B = Bakelite varnish. V = vacuum. b = copper band contacts.
ice for example: *SVb* sapphire base, vacuum type mounting using copper band contacts. Element 178 marked *CAV* was stuck with Araldite only along one edge, and was therefore a semi-vacuum mount.

† Area unobscured by solder.

between the Araldite- and vacuum-mounted bolometers e the varnish-mounted bolometers and bolometer No. 178 :h was stuck with Araldite only along one edge. Bakelite iish proved to be a less good adhesive than Araldite and probably explains the almost vacuum-mounted behaviour oolometer No. 192. There was only one bolometer . 194) for which the frequency response could not be d by any of the curves of Fig. 2.

leasurements of the phase difference between the input output radiation were not possible with the apparatus in but would be an additional check on the theory.

linimum detectable signals for the bolometers were rded but are not strictly within the scope of this paper will be mentioned only briefly. The theoretical limit of ction is a function of the thermal characteristics of the ometer and is set by fluctuations in the heat exchange veen the bolometer and its surroundings. Expressions the magnitude of these fluctuations as a function of uency are given by Milatz and Van der Velden.(7) In tice, however, Johnson noise in the bolometer element urrent or amplifier noise may be the limiting factor. In present work the smallest signals detected were of the er of 2×10^{-9} W/cm² in 1 c/s bandwidth at 800 c/s and limit was set by current noise in the electrical contacts to bolometer elements.

CONCLUSION

he model described in this paper is sufficient to analyse results obtained from all but one of a batch of niobium nitride superconducting bolometers and the quantitative agreement with the known heat capacities of the materials used is good. The theory should apply to most types of solid-backed bolometer in which the design is such that the heat flow is approximately perpendicular to the receiving surface.

ACKNOWLEDGEMENTS

The authors are indebted to their colleagues at the Radar Research Establishment for much help and advice, and particularly to P. B. Bunn, who made many of the bolometers and assisted with the measurements. Acknowledgement is made to the Controller, H.M. Stationery Office, for permission to publish this paper.

REFERENCES

(1) Ministry of Supply, unpublished report.
(2) Milton, R. M. *Chem. Rev.*, **39**, p. 419 (1946).
(3) Andrews, D. H. *Report of an International Conference on Fundamental Particles and Low Temperatures*, Vol. II, p. 56 (London: Physical Society, 1947).
(4) Fuson, N. *J. Opt. Soc. Amer.*, **38**, p. 845 (1948).
(5) Armstrong, G. *J. Amer. Chem. Soc.*, **71**, p. 3582 (1949).
(6) Parkinson, D. H., and Quarrington, J. E. *Brit. J. Appl. Phys.*, **5**, p. 219 (1954).
(7) Milatz, J. W., and Van der Velden, H. A. *Physica*, **10**, p. 369 (1943).

A personal γ-radiation monitor with audible warning device

By D. Allenden and I. W. Collip, Research Laboratory, Associated Electrical Industries, Ltd., Aldermaston, B

[*Paper first received* 24 *June, and in final form* 7 *December*, 1955]

A prototype personal γ-radiation monitor is described, which uses an electrometer valve and transistor alarm circuit to give an audible warning to the wearer on receipt of a tolerance dose of γ-radiation. The insulation requirements of the valve and chamber circuits and the design of the alarm circuits are discussed, particular attention being paid to ease of checking and "fail-safe" features. It is concluded that the desired performance is consistently realizable in the design presented, a dosage accuracy of the order of ±5% being achieved.

1. INTRODUCTION

Personnel working in regions of high γ-radiation need the protection of some type of personal monitoring device. This need has hitherto been met by the use of dosimeters of the quartz-fibre type(1,2) which have the disadvantage that they must be read by the wearer. For very high and variable radiation levels, such as are encountered, for example, in the exhaust systems of atomic plants, it is desirable to have a definite audible warning when the worker has received tolerance dosage. Quartz-fibre electrometers in which the movement of the quartz fibre is used to switch on a buzzer or oscillator have been produced,(3,5) but suffer from disadvantages inherent in the manufacture of the quartz-fibre switch. The prototype 1297A monitor described in this paper presents an alternative solution to the problem which has received little attention.(4)

2. OUTLINE OF OPERATION

Incident radiation falls on a sealed ionization chamber containing de-humidified air at atmospheric pressure. In addition to the collector plate, the outer case of the chamber houses a subminiature electrometer valve, the grid and cathode of which are normally connected respectively to the collector plate and the (earthy) chamber casing, as shown in Fig. 1. The chamber is initially charged to some 50 V, the collector being negative, so that the valve is cut-off by some twenty times its grid base. Incident γ-radiation produces ionization causing discharge of the chamber, the reduction of chamber voltage being a direct measure of integrated dosage. The constants of the system are so chosen that exposure to the tolerance dosage of 100 mr the anode c in the valve is initiated and this actuates the alarm osci *via* a trigger circuit, the only function of which is to pr a "snap-action" alarm.

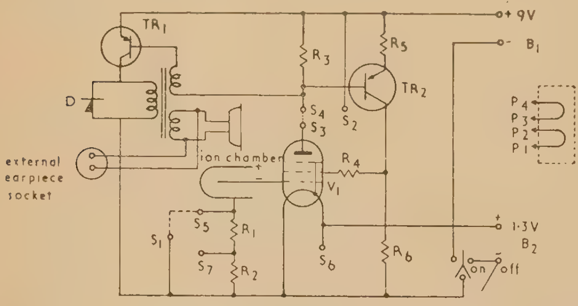


Fig. 1. Circuit diagram of production prototype personal γ-monitor

R_1 = 1 MΩ
R_2, R_3 = 100 kΩ
R_4 = 33 kΩ
R_5 = 2·7 kΩ
R_6 = 33 kΩ

TR_1, TR_2 = OC71

D = CG4 (CV448)

V_1 = CV2348

B_1 = B1497
B_2 = Mallory RM12

S_1–S_7 = connexions to charging socket
P_1-P_4 = plug pin numbers which correspond with socket numbers

3. DETAILED DESIGN

3.1 *Ionization chamber design.* The capacitance C voltage change (ΔV), volume v (cm^3), and radiation d are related by(4):

$$r\ (\text{röntgens}) = 3C.\Delta V/1000\ v \text{ at N.T.P.}$$

A minimum value of ΔV is determined by the ne reduce to at least 2½% variations in dosage sensitivity by production spreads in valve cut-off voltage. measurements on a number of valves, a nominal figu 50 V was chosen.

In a portable instrument severe restrictions are place the volume of the chamber: at the same time this dema

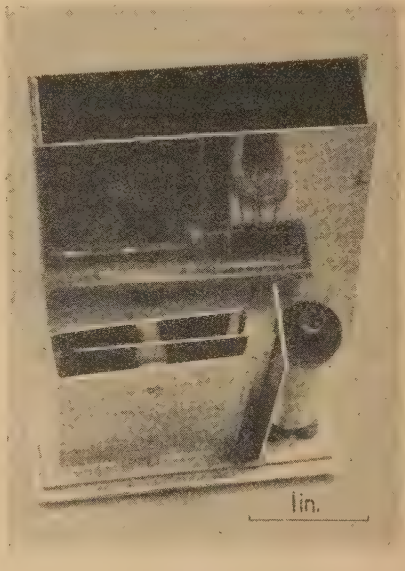
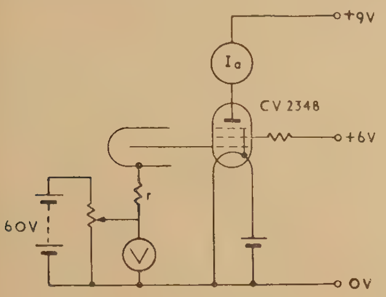


Fig. 2. Prototype ion chamber with electrometer va in position

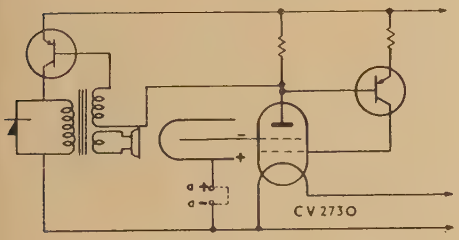
lower capacitance, with consequent higher insu resistance if leakage is to be kept down to a reasonable l The values chosen for C (20 pF) and v (30 cm^3) represe compromise between these conflicting requirements.

The final chamber design is shown in Fig. 2. In the pr type instruments these were assembled from 0·02 aluminium using ultrasonic soldering techniques, and se casting resin. It is expected that production instruments ncorporate pressed and welded chambers.

Ionization chamber and electrometer insulation. The ation resistance must be high enough to reduce the loss ltage by an un-irradiated chamber to less than 5% of nitial charging voltage, if a dosage accuracy of 5% is realized. This demands a leakage time-constant of oximately 200 hours and since the chamber capacitance ed at 20 pF from other design considerations, a leakage ance of at least 4 × 10^{16} Ω is required. Since it was m(3) that resistances in excess of this could be realized ing polytetrafluorethylene supports for the ion chamber ctor, the anticipated difficulties lay in the realization of iently low grid current and surface leakage in the valve. nformation on these factors was available for the special ating conditions where the valve is biased well past cut-nd an extensive series of tests was carried out to deter- whether or not a suitable valve existed. As a first ure it was decided to house the valve inside the chamber o fill the latter with de-humidified air. This construction avoided the need for a very low leakage lead-through ator in the chamber wall and provided complete electro- screening. The tests consisted of measuring the loss harge on complete chamber-valve assemblies under us ambient conditions, using the circuit shown in 3(*a*). The chambers were charged by inserting a known age, polarity as indicated, in the "earthy" lead of the nber.(4) This ran the valve into grid current (limited to fe value by *r*), charging the chamber to the input voltage the (unknown) valve grid base, the small anode current ch flowed subsequently being noted. The charging age was then removed, and the chamber case earthed, ing the valve heavily cut-off. The loss of voltage at any thereafter was determined by inserting a variable-voltage he earthy end of the chamber and slowly increasing this l an anode current, equal to that noted on initial charge, obtained. The voltage required to produce this current less than the initial charging voltage by an amount equal to the chamber loss. This technique is also used in the actual monitor as a means of charging, of checking leakage and measuring "partial" doses.



(*a*)



(*b*)

g. 3. (*a*) Method of measuring loss of chamber voltage.
(*b*) Trigger circuit with tetrode electrometer

The tests established that two available valve types, the type CV2730 (ME1402) and type CV2348 (ME1403), were suitable, and the latter valve was chosen for the prototype instruments. With these valves insulation resistances of from 10^{17} Ω to 4 × 10^{17} Ω independent of ambient conditions were consistently realized provided that the chamber was effectively sealed and light-tight. The resistances realized did not differ significantly whether the valve filaments were on or off, showing that true grid current made a negligible contribution to the leakage.

3.3 *Alarm circuit.* The main requirements for the alarm circuit were as follows:

(i) should give a clearly audible warning on receipt of tolerance dosage;

(ii) should give a "safe" note of much reduced volume and frequency, prior to the receipt of tolerance dose, such indication to be so arranged that power supply or component failure will cause either its cessation or a sufficiently large change of frequency to draw the attention of the wearer;

(iii) power supply drain to be low, and should utilize the same batteries as the electrometer valve.

After a brief consideration and rejection of valve circuits, the transistor alarm circuit, using junction transistors shown in Fig. 1, was devised. Transistor TR_1 works in a conventional blocking-oscillator circuit, and feeds a deaf-aid type earpiece. When V_1 is non-conducting the base of TR_1 is returned to the positive line *via* R_3: the transistor oscillates at a very low frequency since it is self-biased almost to emitter current cut-off. An increase of base current, such as would be produced by conduction in V_1, raises the frequency. There remains the disadvantage that the change is gradual and may not be very apparent. To accelerate the transition a second transistor TR_2 is incorporated. This, with the anode and screen of the valve, forms a bi-stable flip-flop in which the regenerative loop is normally kept open by V_1 being cut-off. Conduction in V_1 raises base and collector currents in TR_2, raising V_1 screen voltage and further increasing anode current. The action is cumulative and V_1 snaps over to the fully-conducting state. Screen resistor R_4 prevents the valve current rising to the level at which the alarm note goes above audibility.

The only failure which does not produce the desired cessation or change of "safe" note is the filament or filament supply to the valve. The latter possibility is covered by the system adopted for routine checking. It is expected that valve filament failures will be rare if valves are replaced after an appropriate service life. However, it is possible to obtain indication of filament failure with the type CV2730 tetrode valve by using the circuit shown in Fig. 3(*b*). The space-charge grid of this valve draws continuous current even during anode cut-off, and the grid-filament path can be used as the collector load of TR_2. Failure of this circuit then disconnects TR_2 collector, and this can be arranged to stop oscillations in TR_1.

4. CONSTRUCTION, POWER SUPPLIES AND OPERATION

The instrument is self-contained in a standard plastic deaf-aid case from which it is easily removable to allow the case to be de-contaminated. A socket is provided so that an extension earpiece can be used in noisy situations. A single Mallory type RM12 cell supplies the valve filament current (8 mA) whilst valve and transistor high tension is supplied by a 9 V layer type battery. Total current in the "safe" condition is about 150–200 μA. Since no means of determining the life expectancy of a Mallory cell has been devised, a high-tension battery has been chosen which under normal conditions has a shorter life than the type RM12. Replacement of *both* batteries when the high-tension voltage falls below 7 V provides a suitable safeguard against filament supply failure.

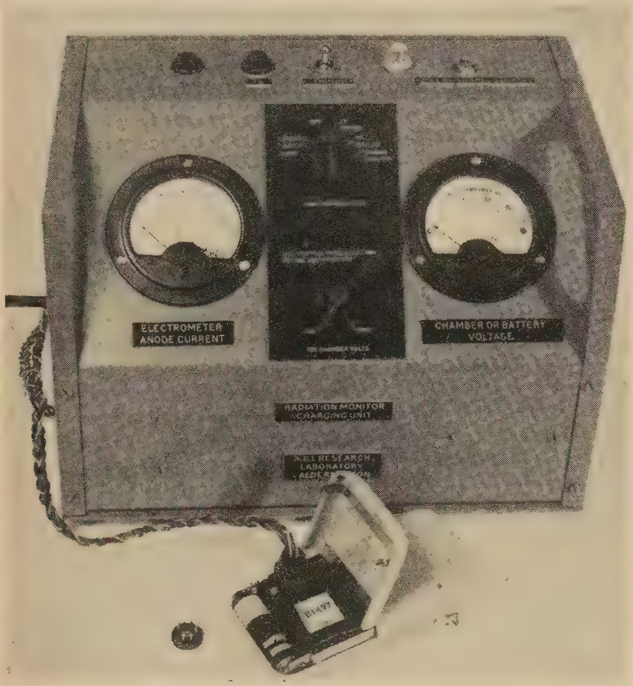

ELECTROMETER ANODE CURRENT
CHAMBER OR BATTERY VOLTAGE
RADIATION MONITOR /CHARGING UNIT
A.E.I. RESEARCH LABORATORY

Fig. 4. Monitor and charging unit

In operation, the chamber is initially charged as described in Section 3.2, the final calibration being carried out by adjustment of the charging voltage. In the prototype instruments a dummy plug was removed and a lead from the charging unit plugged into the vacated socket, although it is expected that the plug will be superseded in production instruments by a system of contacts actuated by the lid
battery compartment. In addition to a fixed-voltage cha
supply, the charging unit incorporates facilities for le
and power-supply checking and measurement of partial
Fig. 4 shows the monitor and charging unit.

The four prototype units so far constructed show
calibration spread of less than 5%, and, if 10% tole
resistors were employed, would function with any trans
of types OC70 and OC71.

5. CONCLUSIONS

The type 1297A personal γ-monitor provides a mea
giving to the wearer an audible warning when the
radiation dosage has been reached. It is likely to
applications in all fields of nuclear activity where
γ-radiation levels are encountered. Its circuitry is relat
simple, largely self-checking and intrinsically safe.

ACKNOWLEDGEMENTS

The development of this monitor to the prototype
was carried out on behalf of the Edison Swan Electric
for the U.K. Atomic Energy Authority. The aut
acknowledge the interest and valuable assistance of M
M. E. Haine and M. W. Jervis of this Laboratory, M
Whiting and Dr. J. Stephen of the Atomic Energy Rese
Establishment, Harwell, and Mr. S. N. Pocock, late o
Edison Swan Electric Co. They are indebted to the
Atomic Energy Authority, the Edison Swan Electric Co.
to Dr. T. E. Allibone, Director of this Laborator
permission to publish this paper.

REFERENCES

(1) Taylor, D. *J. Sci. Instrum.*, **27**, p. 81 (1950).
(2) Taylor, D. *Proc. Instn Elect. Engrs*, **98**, (2), p. 174 (1
(3) Pocock, S. N. Edison Swan Electric Co. *Rese
Report No. SPR* 126, April 1954.
(4) Bell, D. R. U.S. Atomic Energy Commiss
Declassified report, No. MDDC-1180.
(5) Cooke-Yarborough, E. H., Florida, C. D., Stephen, J. H. *Proc. Instn Elect. Engrs*, **101**, p. 288 (1954).

Laboratory and workshop notes

Large liquid-filled plastic lenses

J. W. Telford, B.Sc., and N. S. Thorndike, Division
Radiophysics, Commonwealth Scientific and Industrial
Research Organization, Sydney, Australia

[*Note received* 30 *August*, 1955]

ıe course of experimental work the authors had need for ight-inch condenser lens. The following constructional ıod was devised and may be helpful to others who need ·ge cheap lens. The principle employed is the same as used commercially for television magnifying lenses* but special equipment is needed. The material used is cinal paraffin oil or water retained by a clear, $\frac{1}{16}$ in. :, Perspex sheet which, when plastic from heating, is ıed into spherical surfaces by air pressure.

mould is made by cutting circular holes of the desired ture in the centre of two square pieces of plywood, a re having been chosen of sufficient size so as to leave ıt two inches of wood at the narrowest place. The holes ld match when the edges of the square are in alinement. of these pieces is attached to short legs about 3 in. and is provided with guide pieces on the edges to locate other half of the mould when placed on top of it.

wo square pieces of clear Perspex, of slightly smaller ensions than the wooden squares, are cut and then ıed by careful washing with soap and water, and dried soft, clean towel.

form the pieces of Perspex into the required shape they t be heated to just above the boiling point of water, ed in the mould between the wooden formers, and the on between the sheets inflated with compressed air. It found that the heating could be achieved quite satis- orily by a pair of 1 kW electric radiators about 9 in. t; this is sufficient for each square foot of Perspex. A t of clean tin-plate beneath this protects the bench and cts the heat which would otherwise be lost. The Perspex be held, with protective gloves, in the oven so formed, constantly turned around to obtain uniform heating. n it has lost all its rigidity and is completely "rubbery" hot enough for the next stage.

ıe pieces of Perspex are quickly dropped on to the om half of the mould, after a long hypodermic needle, an attached rubber tube, has been placed between them. top is immediately placed on the mould and the sandwich ıped around the edges. The Perspex is then inflated with rom some convenient source. The authors found it easy djust the air pressure by holding the rubber tube on the odermic needle against the outlet of an air hose. Owing ıe air leakage around the needle, the air must be con- ously supplied until the Perspex has cooled. Great care t be exercised not to blow the Perspex out further than ired, as the spherical shape cannot be preserved if the depth is reduced after cooling has decreased the plasticity e edges.

fter the Perspex has cooled, location holes should be ed through the mould and the Perspex before the clamps emoved. The flat edges of the Perspex are then wetted ethylene dichloride and the two halves stuck together, the mould again used for clamping, the pins through the ion holes ensuring correct alinement. The ethylene oride is best applied with a brush as it must be done very quickly to avoid complete evaporation of the solvent. When the joint is dry, the assembly may be screwed together by metal screws through the location holes.

After the lens has been filled with paraffin or water through the hypodermic needle it is ready for use. It was found that paraffin could be readily injected through the needle by employing a length of $\frac{1}{2}$ in. bore brass tube as a syringe, one end being threaded to fit the air hose and the other attached to the hypodermic needle. The air pressure can be used to overcome the viscosity of the paraffin more readily than the pressure of the fingers can operate a hypodermic syringe. The normal hypodermic syringe is used to inject water.

Measurements with a spherometer on an 8 in. diameter lens indicate errors in radius of curvature of less than the measuring error of 5% for the middle 4 in. diameter, but appreciable errors are noticeable within 1 in. of the edge.

The work described in this paper was carried out as part of the programme of the Division of Radiophysics of the Commonwealth Scientific and Industrial Research Organization, Australia.

---

* *Modern Plastics*, **25**, pp. 114–116 (1948).

Measurement of the damping of metal bar specimens in mechanical resonance

By H. Pursey, B.Sc.(Eng.), and E. C. Pyatt, B.Sc.(Eng.),
A.M.I.E.E., National Physical Laboratory, Teddington,
Middlesex

[*Note first received* 6 *June, and in final form* 7 *July*, 1955]

In a previous paper* we described apparatus for the determination of the elastic constants of metal bar specimens by measurement of their natural resonance frequencies. Additional circuits have now been added to enable the Q-value of the specimen to be measured also, as detailed below.

For specimens of low Q (up to 3000–4000) a 3 dB pad can now be introduced into the detector amplifier circuits, so that the bandwidth of the specimen resonance curve for 3 dB below the maximum can be rapidly determined. The frequencies are measured as previously on a six-decade counter equipment, started and stopped by accurately timed one second pulses. The Q-value is given by f/δ where f is the resonance frequency and δ is the bandwidth for a 3 dB reduction in response.

For specimens of higher Q this method is no longer satisfactory, as the bandwidth becomes too small to be measured easily. The alternative method we have used is to measure the time taken for the output from the specimen to decay between two fixed voltages, when the excitation is suddenly removed. Apparatus based on similar principles has already been described by Fusfeld.† The 1 Mc/s output which we normally feed to the display cathode-ray oscilloscope is rectified in a voltage doubler arrangement using a double diode (type CV 140). The use of the fixed frequency limits the error due to the time constants of the rectifier circuits to a value independent of frequency and removes the need for switching time constant circuits when the frequency is changed.

The rectified output voltage, which is negative, is smoothed and applied to the Q measuring unit, where it appears across two 470 kΩ precision resistors in series. Two identical trigger circuits are provided, which change state and deliver a pulse at the output when the input voltage passes through a predetermined value. One is connected across both resistors, the other across one of them. The principle of

---

* Pursey, H., and Pyatt, E. C. *J. Sci. Instrum.*, **31**, p. 248 (1954).

† Fusfeld, H. I. *Rev. Sci. Instrum.*, **21**, p. 612 (1950).

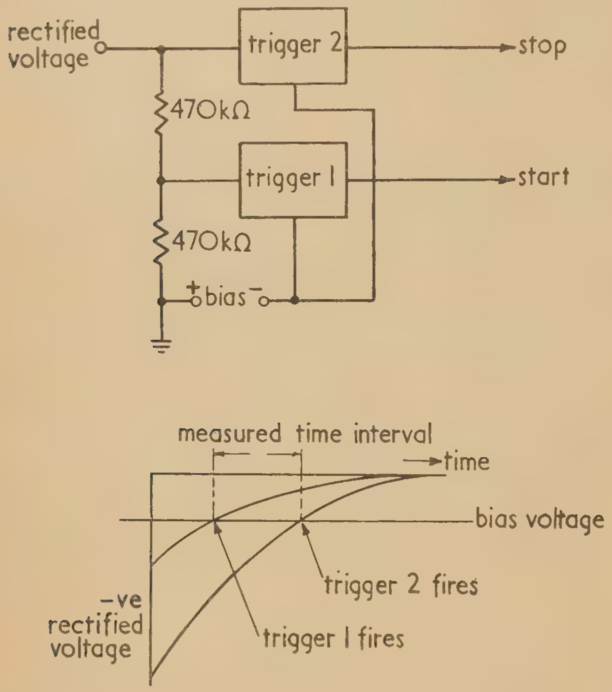

rectified voltage
trigger 2
stop
470kΩ
trigger 1
start
470kΩ
+ bias −
measured time interval
time
bias voltage
trigger 2 fires
−ve rectified voltage
trigger 1 fires

Fig. 1. Diagram showing principle of operation

operation is shown in Fig. 1. While the excitation is pr
the negative voltage derived from it exceeds the value o
bias voltage and neither trigger operates. When the excit
is removed, the specimen output decays and the rec
voltage becomes less negative. When the bias voltage
half the rectified voltage equals the trigger firing vol
trigger 1 operates and delivers a “start” pulse to the
decade counter. The rectified voltage continues to fall
the time is reached when rectified voltage plus bias vo
equals the trigger firing voltage. Now trigger 2 operates
delivers a “stop” pulse to the counter. This is counti
1 Mc/s crystal controlled oscillator, so that the co
indication gives the time interval between “start” and “s
pulses in microseconds. The value of Q is then give
$\pi f T/\ln 2$, where f is the resonance frequency and T
measured time interval.

Fig. 2 gives full details of the circuits and the power sup
The trigger circuits are of conventional type using d
triode type CV 858; an input cathode follower preven
flow of grid current in the 470 kΩ resistors, an output cat
follower acts as buffer between trigger and counter.
main power supply is a conventional stabilized circuit u
CV 2179 as the series valve, CV 138 as the control valve
CV 449 as the voltage standard. The bias supply is r
complex. It has to be variable and, since it provides
earth return path for all the trigger circuits, must also ha
very low output impedance to avoid hum pick-up.
signal output is set to the maximum possible point w
the linear range of the signal amplifiers, i.e. as far as pos
in excess of the system noise level; the bias voltage is
set appropriately. The variable bias arrangement
enables the shape of the decay curve to be determine
desired.

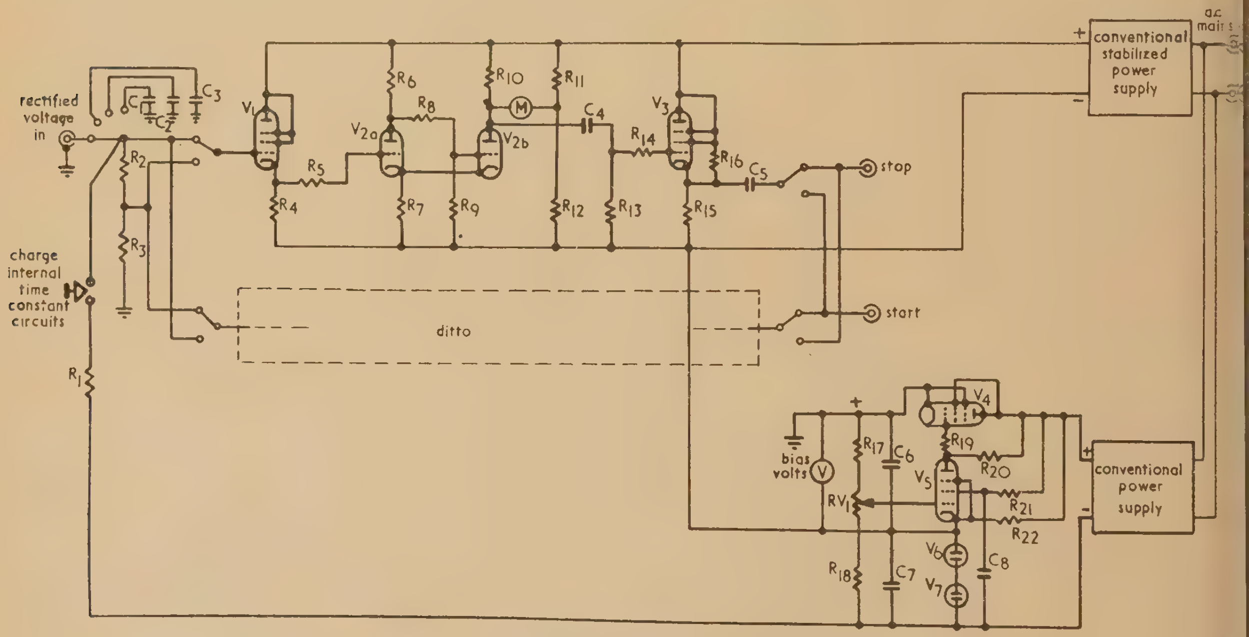

rectified voltage in
C1
C2
C3
R2
R3
charge internal time constant circuits
R1
V1
R4
R5
V2a
V2b
R6
R7
R8
R9
R10
M
R11
C4
R12
R13
R14
V3
R15
R16
C5
stop
start
ditto
a.c. mains
+
conventional stabilized power supply
−
bias volts
V
RV1
R17
C6
R18
C7
+
V4
R19
V5
R20
R21
R22
V6
V7
C8
+
conventional power supply
−

Fig. 2. Circuit diagram of the equipment

$R_1 = 3$ kΩ
R_2, $R_3 = 470$ kΩ
$R_4 = 20$ kΩ
$R_5 = 100$ kΩ
$R_6 = 47$ kΩ
$R_7 = 3{\cdot}3$ kΩ
$R_8 = 150$ kΩ
$R_9 = 33$ kΩ
$R_{10} = 10$ kΩ
$R_{11} = 68$ kΩ

$R_{12} = 180$ kΩ
$R_{13} = 100$ kΩ
$R_{14} = 20$ Ω
$R_{15} = 4{\cdot}7$ kΩ
$R_{16} = 100$ kΩ
$R_{17} = 39$ kΩ
$R_{18} = 133$ kΩ
$R_{19} = 4$ kΩ
R_{20}, $R_{21} = 150$ kΩ
$R_{22} = 47$ kΩ

$RV_1 = 100$ kΩ

$C_1 = 0{\cdot}01$ μF
$C_2 = 0{\cdot}1$ μF
$C_3 = 1$ μF
C_4, $C_5 = 100$ μμF
$C_6 = 4$ μF
$C_7 = 8$ μF
$C_8 = 0{\cdot}01$ μF

V_1 = CV138
$V_{2a,\,2b}$ = CV858
V_3 = CV138
V_4 = CV2179
V_5 = CV138
V_6, V_7 = CV286

conjunction with the 470 kΩ resistors stable precision ensers provide internal time constant circuits for adjust- and calibration. The circuit positions of the two ers can be interchanged and a control is provided to e them to be set to identical operating points. When ctly adjusted, interchanging the triggers will not affect neasured time-interval. Arrangements have also been d for the automatic repetition of the measurement cycle gular time intervals.

e following sources of error are possible. Random s will arise from hum (special power supply circuits have used as described) and mechanical vibration (the uring head is now mounted on a robust anti-vibration nting). These are averaged by taking a series of observa- where possible. Systematic errors may arise in the er chain (i.e. the 470 kΩ resistors) and also owing to inearity in the system amplifiers. Taking all these bilities into account the accuracy may, under good itions, be as high as 1%, but this depends a great deal e actual specimen. External damping from the trans- circuit, the mechanical supports and the surrounding rovides a further possibility of error difficult to assess or nate.

wish to acknowledge the helpful suggestions of Mr. G. field, Physics Division, National Physical Laboratory, g the course of the development. The work described e has been carried out as part of the research programme National Physical Laboratory and this note is published rmission of the Director of the Laboratory.

imple method of controlling the temperature of a prism

K. P. Norris, B.Sc., Ph.D., Microbiological
esearch Department, Ministry of Supply, Porton,
Wilts.

[*Note received 5 October*, 1955]

y present-day infra-red spectrometers rely upon some anical or electrical cam mechanism to provide a constant length or wavenumber scale. The form of the cam is a lex function of the refractive index of the prism material for a given prism, the cam is correct only when the erature of the prism is maintained constant at the value in calculating the form of the cam. In a double-beam ment, where the atmospheric absorption bands are lled out so that there is no internal wavelength cali- on, it is even more important that the prism temperature not change.

e prism heaters of an infra-red monochromator are ly mounted inside a rigid hollow casting which carries top surface the prism and the other optical components. is generated in the prism as a result of the absorption ht, but most of the heat required to keep the prism at a ant temperature is supplied by the heaters. For the olling device to be sensitive to temperature variations g from the irradiation of the prism it is essential to have ntroller in thermal contact with the prism. Under these tions, and with the heaters under the base of the mono- ator, there is a considerable time lag between the rs being switched on and the heat reaching the prism ontroller. This, combined with the fact that the base of the monochromator has a large thermal capacity, gives rise to temperature fluctuations which are considerably greater than the differential of the controller. The prism temperature variation in a Grubb–Parsons monochromator is approximately 0·6° C when a sensitive thermostat in contact with the baseplate of the prism is used to control the heaters. This variation can be reduced by placing the temperature controlling element in contact with the heating coils, but under these conditions the thermostat is insensitive to temperature changes produced by irradiation of the prism or by other external causes. As heat is supplied only to the base of the prism, the periodic variation in temperature changes in phase, and is considerably attenuated as it moves up the prism. This gives rise to complex temperature variations within the prism which are detrimental to resolution as well as to wavelength calibration. The thermally ideal arrangement is to have heaters spaced around the prism but optically this is not very convenient. The object of the present note is to describe a simple method which, whilst not being perfect, is a satisfactory compromise between the thermal and optical requirements.

An electronic relay (type E.A.3 by Sunvic Controls Ltd.) operated by a mercury contact thermometer (by Electro Methods Ltd.) is used to control the supply of current to the heating coils. The metal baseplate of the prism is extended near the apex to provide a socket for the bulb of the contact thermometer so that the baseplate and the thermometer are in good thermal contact. A small heating coil made from 30 cm of 24 s.w.g. double-silk covered Eureka wire with a resistance of 0·57 Ω is wound round the bulb of the contact thermometer and wired in series with the main heater. The resistance of the coil is so calculated that heat is generated in the coil at a rate sufficient to raise the bulb of the contact thermometer approximately 0·01° C (the differential of the controller) in thirty seconds, since from previous experiments it had been established that, when the main heaters were on, the temperature of the prism increased by 0·01° C in thirty seconds. The time lag between the current in the heating coil being switched on and the heat arriving at the prism is effectively eliminated by supplying heat to the controller at the same rate as it is supplied to the prism. In this way the temperature variations of the prism are reduced to the limit set only by the differential of the controller. If the rate of supply of heat to the controller is less than that to the prism then the temperature variation is less than 0·6° C but greater than 0·01° C, whereas if the rate of supply of heat to the controller is much greater than that to the prism it is not possible to maintain the prism at the desired temperature.

When the instrument is in use and radiation enters the monochromator the temperature is controlled to ±0·025° C; with no radiation falling on the prism the control is much better, being of the order of ±0·005° C. Lagging the monochromator helps to reduce the temperature difference between the top and bottom of the prism, but it prevents the escape of heat generated in the prism by irradiation. Even with a small amount of lagging it is found that the heat losses are less than the heat generated in the prism and the temperature of the prism continues to rise when the heaters are switched off. For this reason no lagging is used but the temperature difference across the prism has been reduced to less than 0·2° C by placing a bridge of $\frac{3}{16}$ in. thick copper sheet from the top to the bottom of the brass prism mounting.

Correspondence

Correction of millimetre mercury barometers

British Standard 2520: 1954 *Barometer Conventions and Tables* contains tables for the correction of barometers which are of general use because of the wide range of values covered. However, the tables are applicable to conventional barometers which have scales calibrated at 0° C, whereas the experimentalist who sets up his own barometer usually uses a millimetre scale (either as part of a cathetometer or set up adjacent to the mercury column) which is calibrated at 20° C, the temperature of adjustment for scales in general. The effect of changing the temperature of calibration may be important in precise measurements; for example, it amounts to nearly 0·3 mm at 760 mm for a brass scale. McGlashan, Prue and Sainsbury* mentioned this recently but it seems worthy of wider attention.

Values of barometric height obtained with a brass scale ($\alpha = 0 \cdot 000\,018\,4$ per °C) calibrated at 20° C may be corrected for temperature in the following ways. (It is assumed that scale and barometer are at the same temperature; even if they differ slightly this is normally justified by the relatively small effect of expansion of the scale compared with that of the mercury.)

1. Apply the correction for a Fortin barometer and multiply the value so obtained by 0·999 632 (the factor only varies by 1 part in 10^7 over the range 10 to 30° C).
2. Obtain the correction by entering the Fortin table 2·3° C above the actual temperature of the manometer.
3. Obtain the correction from the empirical expression

$$\Delta h = -(t + 2 \cdot 5)h/6\,200 \text{ mm}$$

where h mm is the observed height of the column and t° C is the temperature. This expression is easy to remember and convenient for use with a slide rule. It has been deduced, by applying method 2, from the fact that at 620 mm the tabulated correction for a Fortin barometer is given by $(t + 0 \cdot 2)/10$ between 10° C and 35° C, and it may be shown that it is rarely in error by as much as 0·01 mm.

When a steel scale ($\alpha = 0 \cdot 000\,011$ per °C) is used the adjustment is in general more complicated. At 20° C, the temperature of calibration, the factor (method 1) is 0·999 632 as for the brass scale, but it varies from 0·999 71 to 0·999 56 over the range 10 to 30° C. The temperature additions for method 2 are 1·8 at 10° C, 2·3 at 20° C and 2·7 at 30° C. Method 3 can be applied but the formula is dependent on the temperature of observation.

Measurements have also to be corrected for gravity. For this purpose the ordinary barometric gravity-correction tables may be used. It is worth noting, however, that in the south of England the net result of applying both the gravity correction (which depends on the ratio of local gravity to standard gravity 980·665 cm/s^2) and the factor 0·999 632 used in method 1 of temperature correction is very small. For example, at Teddington, where $g = 981 \cdot 183$ cm/s^2, the gravity ratio is 1·000 53 which, when multiplied by 0·999 632, gives 1·000 16. If the difference of this combined factor from unity is of significance the factor can be applied directly, or, if desired it can be dealt with by entering the ordinary gravity-correction table at an appropriately reduced value of
example, at $h \times 16/53$ (i.e. $0 \cdot 3h$) for observations at Te
ton. Obviously, the method of applying these corre
will depend on whether the arithmetic is performed me
or mechanically.

This letter is published by permission of the Director
National Physical Laboratory and of the Director
Chemical Research Laboratory.

Chemical Research Laboratory, D. Ambr
Teddington, Middlesex.

National Physical Laboratory, P. H. B
Teddington, Middlesex.

---

* McGlashan, Prue and Sainsbury. *Trans Faraday Soc.*, **50**, p. 1284 (1954).

A liquid scintillator containing nitrogen

In connexion with photo-disintegration experiments*
ducted in this laboratory, a liquid scintillator was rec
with a high nitrogen content and with only carbo
hydrogen in addition. Consideration of boiling
stability and nitrogen content suggested ethylene di
($C_2H_4 . 2NH_2$) and acetonitrile ($CH_3 . CN$) as worth
gation. Redistilled samples of these two liquids
saturated with scintillation grade *p*-terphenyl, with di
hexatriene added at a concentration of 10 mg/l. and en
in sealed glass cells. An identical cell containing 4 g
p-terphenyl and 10 mg/l. diphenyl hexatriene in toluen
used for comparison. The measurements were made
type 6260 photomultiplier (by Electric and Musical Indu
Ltd.); the calibration γ-ray source was ^{137}Cs (663 keV).

Ethylene diamine. Three or four hours after prepar
this gave pulse heights about 5% of those from *p*-terp
in toluene. The pulse height decreased with time and tw
four hours later could not be distinguished from tube
This effect is probably due to hydrolysis of the eth
diamine during preparation of the scintillator.

Acetonitrile. This scintillator gave pulse heights abou
of *p*-terphenyl in toluene. A saturated solution of *p*-terp
in acetonitrile contains only about 0·9 g/l. Improveme
pulse height may be achieved at the expense of some nitr
content by adding toluene, enabling a higher concentr
of terphenyl to be incorporated in the scintillator.
saturated solution of *p*-terphenyl in a 75 : 25 acetoni
toluene mixture contains about 2 g/l. and gave pulse he
about 25% of those from the pure toluene standard.
performance has been maintained over a period of eig
months. The scintillator does not necessarily represen
optimum conditions of nitrogen content and pulse he
but since it was satisfactory in performance, no fu
attempt was made to determine those conditions.

The work was performed as part of the programm
the Australian Atomic Energy Commission in the Ph
Department, University of Melbourne. Thanks are du
Prof. L. H. Martin for making available the facilities o
laboratory.

Physics Department, J. R. Presco
University of Melbourne,
Australia.

---

* Campbell, J. G. *Aust. J. Phys.*, **8**, p. 449 (1955).

New instruments, materials and tools

ditor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved cts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

v cathode lamps. Hilger and Watts Ltd., 98 St. Pancras /ay, London, N.W.1.

w cathode lamps having iron or copper cathodes are ble in a permanently sealed off form, so that they may unted on a Barfit stand on a Hilger standard accessory Each lamp is mounted on a plug which fits a socket on arfit stand so that one lamp may be immediately sub- d for another without disturbing any other part of the atus. About 750 V are required for the operation of lamps with their ballast resistors and a compact power or this purpose for operation from mains can be supplied. akers claim that the simplicity, steadiness and fineness lines makes these lamps ideal for producing reference a. They are made with silica windows sealed through led seal so that their usefulness is extended to the ultra- spectrum.

hodes can be made of any element which can be formed cylinder and which does not have too low a melting To obtain spectral lines of elements which are not le for cathodes in the pure state, cathodes can be red from suitable alloys.

ical connectors. Electro Methods Ltd., Caxton Way, tevenage.

ies of connectors, similar to that illustrated in Fig. 1, e in production shortly. These connectors have from 50 contacts, each capable of carrying 7·5 A and with a down voltage between contacts in excess of 3·7 kV. pin contacts are made of brass and the sockets of phosphor-bronze; both are precision machined and gold-over-silver plated to ensure low contact resistance and absence of corrosion. Both plugs and receptacles can be fitted with aluminium hoods and cable clamps.

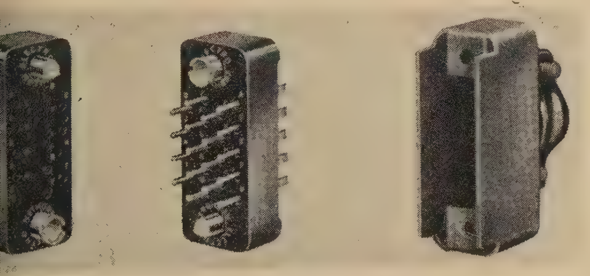


Fig. 1. Multi-way connectors and cable clamp

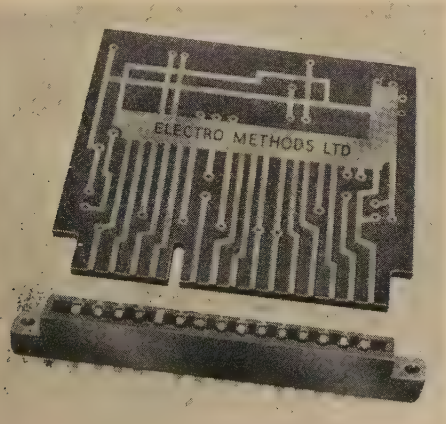
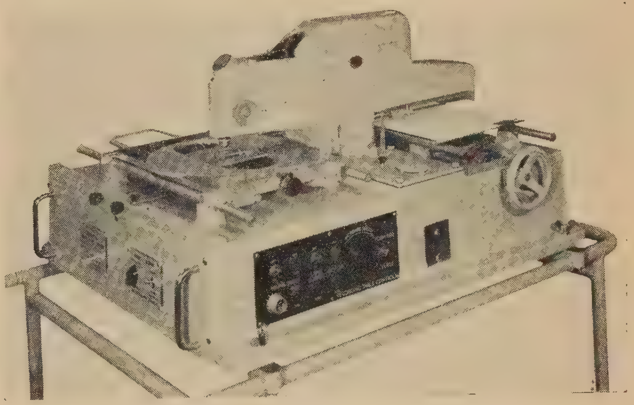


Fig. 2. Connector for printed circuit

A second series of connectors, a typical example of which is shown in Fig. 2, has been designed to form a link between printed circuitry and conventional wiring. They allow instant removal and replacement of the plug-in card, provide positive identification of individual circuits and simplify the attachment of cable lead-off wires. The connectors have $\frac{5}{32}$ in. centre-to-centre contact spacing, and the contacts are rated at 5 A. The connectors will be available with 6, 10, 12, 15, 18 and 22 contacts.

Automatic recording microdensitometer. Joyce, Loebl and Co. Ltd., Vine Lane, Newcastle upon Tyne 1.

This instrument, illustrated in the figure, is of the double-beam, null-point type, the density being recorded by a pen attached to the self-balancing optical attenuator. The object and record tables are coupled directly by a lever having a number of fixed ratios from 1 : 1 to 16 : 1 (higher ratios can be incorporated on request). The main feature claimed for the instrument is the high accuracy combined with speed, the response time for a full-scale deflexion of 7 in. being 0·5 s. The plate or film holder may be rotated through 360 degrees and provision is made for a movement of 1¼ in. on either side of the centre in a direction at right angles to the direction of scanning. Standard 10 × 8 in. plates may be used as well as smaller plates or films for which a special holder is provided. The sensitivity and resolution of the instrument can be varied by the use of interchangeable objectives and aperture slits. The latter are mounted on a rotary selector plate which also serves as a screen on which the magnified object is focused. The range can also be varied by the use of interchangeable grey wedges of various ranges. The amount of light in the object beam can be varied by neutral density filters and this can be balanced by a polaroid control in the reference beam. The detector is a nine-stage photo-multiplier. The amplifiers, power supplies and motor drive are housed in the base of the instrument, which can be supplied either for bench use, as illustrated, or for trolley mounting.



Double beam recording microdensitometer

Notes and comments

Meteorological Office annual report for 1954–5

The annual report of the Director of the Meteorological Office for the year ending 31 March, 1955 (H.M. Stationery Office, price 2*s.* 6*d.* including postage) describes the work which has been maintained and includes an account of the research programme. Considerable progress has been made in the study of "numerical weather forecasting" in which an electronic computer is used to produce maps of the pressure field twenty-four hours ahead by step-by-step integration of the equations of motion. Another important investigation which is being undertaken is a long series of carefully controlled trials of the possibility of increasing rainfall by seeding suitable clouds with silver iodide particles released from ground generators.

Development was continued of instruments mentioned in previous reports, such as the radar sonde equipment and aircraft instruments which are intended to give meteorological information well into the stratosphere.

Permanent display of British scientific instruments

On 9 February last there was opened at SIMA House, 20 Queen Anne Street, London, W.1, a display of selected items from the products of the member firms of the Scientific Instrument Manufacturers' Association of Great Britain Ltd. The object of the display is to provide a centre where overseas visitors can see a representative selection of instruments, and an extensive catalogue library is being assembled to aid enquirers. The centre will also serve as a common meeting ground for makers and users of instruments in this country. Since it is impossible to give space to all members at the same time, a rota system has been worked out which will give every member a chance to exhibit, and will also ensure that the character of the display will change frequently.

The Physical Society's annual exhibition of scientific instruments and apparatus

The Physical Society announces that its fortieth annual exhibition will be held at the Royal Horticultural Society's Old and New Halls, Westminster, London, S.W.1, from 14–17 May, 1956 (inclusive).

Tickets for *any one* of the following days are available from the Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7:

Monday, 14 May	2 p.m. to 8 p.m.
Tuesday, 15 May	10 a.m. to 8 p.m.
Wednesday, 16 May	10 a.m. to 8 p.m.
Thursday, 17 May	10 a.m. to 5 p.m.

Members of The Institute of Physics may obtain tickets from the Institute's office. The handbook of scientific instruments and apparatus published in connexion with the exhibition will be available at the beginning of April, price 6*s.*; by post 7*s.* 3*d.*

Symposium on X-ray microscopy and microradiography

A symposium, sponsored by the International Un Pure and Applied Physics, will be held in the Cav Laboratory, Cambridge, from 16–21 August next. Its will include all microscopic methods which employ and sessions are planned on the reflexion, contact an jection methods. Sessions will also be devoted to a tions in biology, medicine, metallurgy and other including industrial applications.

Further details may be obtained from Dr. W. C. Cavendish Laboratory, Cambridge.

Electronics for spectroscopists

If the demand justifies it, the Photoelectric Spectr Group will publish the proceedings of two summer sch electronics for spectroscopists held at University C Southampton. These were concerned with theoretical a of electronics associated with photoelectric instru including ultra-violet and infra-red spectrometers, a. d.c. amplifiers, stabilized power supplies, circuit desig fault-finding in addition to notes on noise, semi-cond feedback and other features.

Those interested are invited to write for further det Mr. K. A. MacDonald, c/o Unicam Instruments Arbury Works, Cambridge.

Erratum

In the fifth paragraph of the review of *Atomic research at Harwell*, on p. 452 of the November 1955 of this *Journal*, reference is made to "the use of the grating in divergent light"; this should have read ". . vergent light."

British Journal of Applied Physics

Contents of the March issue

SPECIAL ARTICLE

Rain—natural and artificial. By R. C. Sutcliffe.

CONFERENCE REPORT

Summarized proceedings of a conference on electron microscopy—G July, 1955. By C. E. Challice.

ORIGINAL CONTRIBUTIONS

Origin and analysis of gas in electron tubes. By S. J. Stoll.

Diffusion (or conduction) along a slightly tapering tube, and its applica the determination of diffusion coefficients. By A. Talbot and J. A. Ki

The wall effect and the viscometry of suspensions. By A. D. Maude an Whitmore.

Coplanar mesh storage. By G. R. Hoffman.

NOTES AND NEWS

Correspondence

The determination of base thickness in alloy junction transistors by From J. Rolfe.

Current distribution in an expanding spark channel. From J. M. Somerv C. T. Grainger.

Decomposition of $CaSO_4 . 2H_2O$ in the electron microscope. From J. H.

A replica technique for "reflexion" electron microscopy. From L. Holla

The square wave response method of analysing process control systems. E. Persson; L. Mandel.

Ferrites in resonant cavities. From R. A. Waldron.

New books Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the princip construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Squa London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicati from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Lond E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addr or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable advance. Single parts, so far as available, may be purchased at 10*s.* each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

A magnetic spectrometer

By D. J. Prowse, B.Sc., Ph.D., H. H. Wills Physical Laboratory, University of Bristol,
and W. M. Gibson, M.A., Ph.D., Physics Department, Queen's University of Belfast

[*Paper received* 6 *October*, 1955]

A little-known type of magnetic spectrometer, for measuring the energy of heavy charged particles, is described. The principle is due to P. H. Fowler; the source is outside the region of magnetic field, which particles enter and leave across a straight boundary; particles of different energies are brought to second-order foci at points along a line which also lies outside the region of magnetic field. The principles and the factors limiting the resolution are discussed briefly. The design and performance of an instrument built for protons of energy up to 8 MeV are described; a resolution of up to 1 in 800 in momentum has been obtained.

types of magnetic spectrometer for measuring the es of nuclear particles have been described in the ure.(1) Each has its own particular advantages and tions. A spectrometer based on a principle due to Fowler is described in this paper; its advantages are he source and detector are outside the magnetic field, t gives an extended spectrum at a single magnetic field, hat it is capable of giving very high resolution. The ple has not been fully described in print, though it has mentioned by Hafner, Donoghue and Snyder,(2) and a ometer based on it has been constructed by Inglis(3); nstrument was used to study the reaction ^{9}Be(d, α)^{7}Li, e resolution obtained was only 1 in 200 in momentum o detailed calculations were apparently made on the mance expected. It has also been used by Gelinas and a(4) in a study of deuteron–beryllium reactions.

his paper the authors quote some of their conclusions, ut going into the details of the calculations made. purpose is to show that the principle has already been to give a resolution of 1 in 800 in momentum, and to be some of the properties expected of this type of ment. Most of the actual calculations may be found hesis by one of the authors.(5)

PRINCIPLE

principle is illustrated in Fig. 1; particles leaving the in different directions pass into the region of magnetic field, emerge, and come to first-order foci at points lying on a cusp-shaped curve. At the apex of the cusp there is a second-order focus, since this is the point where the position of the first-order focus ceases to vary with the directions of the particles as they leave the source. Calculations show that the second-order focus occurs when the angle θ, between the initial particle direction and the field boundary, is $\cos^{-1}\sqrt{\frac{1}{3}} = 54° 44'$, in the simple case where the particles are all of one energy, and there is no fringing magnetic field. Particles of different energy come to second-order foci at different points on a line of gradient $\tan^{-1}\sqrt{\frac{1}{8}} = 19° 28'$; a photographic plate may be placed along this line as a detector to record particles of widely different energies at a constant magnetic field. The size of the image produced on such a plate by a point source is only 0·04% of the radius of curvature of the particles in the magnetic field, when they are admitted over a 10° range of θ. In a later section the authors discuss how nearly they may hope to approach this resolution in practice. The possibility of using a wide angle of acceptance compensates for the absence of focusing in the perpendicular direction.

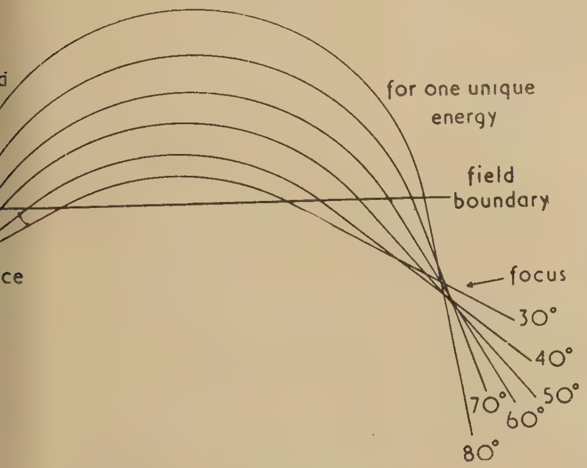


Fig. 1. Principle of the analyser

DESIGN AND CONSTRUCTION

The magnetic field was provided by an electromagnet weighing 2500 lb, with pole-pieces of iron–cobalt alloy 40 × 14 cm. The gap between the pole pieces was 5 mm and the maximum field attainable in this gap was 21 000 G. Except near the edge, the field was found to be uniform to within ±0·3%. The magnet core was made of soft iron plates energized by two air-cooled coils each of 3000 turns. The highest fields required currents of up to 10 A, which could be used only for periods of up to 30 min. Fields up to 16 000 G could be maintained indefinitely.

The source and plate were enclosed in a cylinder above the magnet, as shown in Fig. 2. The pole-pieces themselves formed part of the vacuum chamber, the seal being made with Araldite cement between a Duralumin spacer and the pole-pieces at the bottom and sides, and by a flat rubber gasket between the top and a flat surface milled on the cylinder. A slot in the cylinder allowed particles to leave the sources, follow a path of radius up to 20 cm in the magnetic field, and leave the field to strike the plate. This radius allowed protons or α-particles of energy up to 8 MeV or deuterons up to 4 MeV to be brought to focus. Provision was made for changing the target and for moving the plate sideways from outside; up to eight exposures could be made without admitting air to the system. The angle of the plate and its vertical height could be adjusted within narrow limits. The plate could also be rotated about an axis along the focus line. The purpose of this latter adjustment will be explained later.

The photographic plate detector, in addition to giving permanent record of an extended spectrum, also has the advantage that it can be used with widely different intensities; individual tracks may be counted satisfactorily, so long as there are more than about a hundred in a group, while lines of up to 10 000 times this intensity may be studied by means of the blackening of the emulsion. When individual tracks are examined, their length and grain density can be used to distinguish groups of protons, deuterons and α-particles, even when the groups overlap. Also a track, the length of which is not commensurate with the energy of the particle producing it, determined from its position on the plate, can be rejected as the particle must have been scattered from the edges of the pole-pieces. Discrimination against the background of particles scattered from the pole-piece faces and against particles which have penetrated small thicknesses of matter in their path round the analyser is also assisted by measurement of their angles of entry into the emulsion.

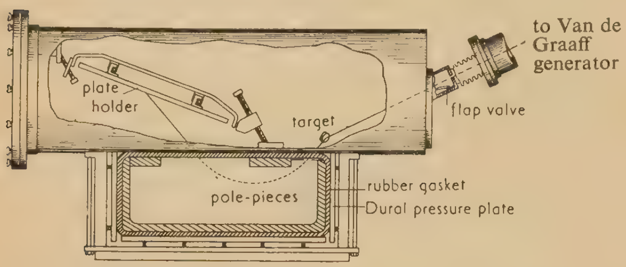


Fig. 2. Diagrammatic view of the vacuum chamber. The beam is shown entering the chamber and striking the target in the plane of the magnet gap. Not shown is a side port which enables the beam to enter in a plane at right angles to the plane of the gap. The target is held in a holder which can be rotated externally

The solid angle over which particles were accepted was initially about 1 in 3000 of the sphere with an aperture of 10°. As there is no focusing in the plane at right angles to the magnet gap, the width of the track on the photographic plate in this direction is determined purely by the geometry of the system and is, in fact, about 8 mm. To reduce the number of particles scattered from the pole-piece faces reaching the plate, a small baffle slit, 3 mm wide was affixed to the edges of the pole-pieces. This reduced the solid angle to 1 in 5000 with a consequent reduction in the width of the trace to 5 mm, the density of tracks remaining unchanged.

The spectrometer has been tested with α-particles from radioactive sources, and with 480 keV deuterons scattered from reflexion and transmission targets; the beam used has been from the small Van de Graaff generator; this beam is at 26·4° from the horizontal, and reaches the target through a port on the end or on the side of the main cylinder.

FACTORS LIMITING RESOLUTION

(*a*) *Homogeneity of the magnetic field.* Measurements with a search coil showed that except in the fringing field, the mean magnetic fields along paths of different particles of the same energy never differed by more than 0·1%. This 0·1% was not due to inhomogeneities in the cobalt iron or to machining errors, but mainly to the bending of the pole-pieces the action of the magnetic field. Spacers were used to r this but it still remained the main cause of field variat the magnet gap.

(*b*) *Control of the magnetic field.* The current was su by batteries with a sensitive potentiometer for indicatin change. With manual control it was not difficult to ke current within 0·05% of the intended value.

(*c*) *Fringing field.* This is comparatively slight with pieces so close together, and general considerations sho the nature of the second order focus cannot be aff Calculations showed, however, that best results wou obtained with particles leaving the source at 50°–52° i of at 54° 44′, and with the plate at a rather greater above the magnet than that given by the simple theory.

(*d*) *Variation of energy with angle of particles source.* This may occur when the particles are the pr of a reaction taking place in a bombarded target. Aga nature of the focus cannot be affected, but its height altered by an amount depending on the direction incident beam, the ratio of the energy released in the re to that of the incident particle, and the ratio of the of the incident and struck particles. As with the fr field the resolution should not be affected if the plate at the correct height. In fact, if the incident beam is angle of about 16° to the beam of particles accepted analyser, calculation shows that, to a first order, the e eliminated. If the beam is at right angles to the magn so that all particles from the target are accepted at 90° incident beam, there is, of course, no variation of energ angle of particles entering the field.

(*e*) *Plate-holder position.* The best value for the holder height depends on factors (*c*) and (*d*), but so lo is within 1 mm of the correct value, a spread correspon less than 0·1% uncertainty in momentum should be obt even with a 10° aperture.

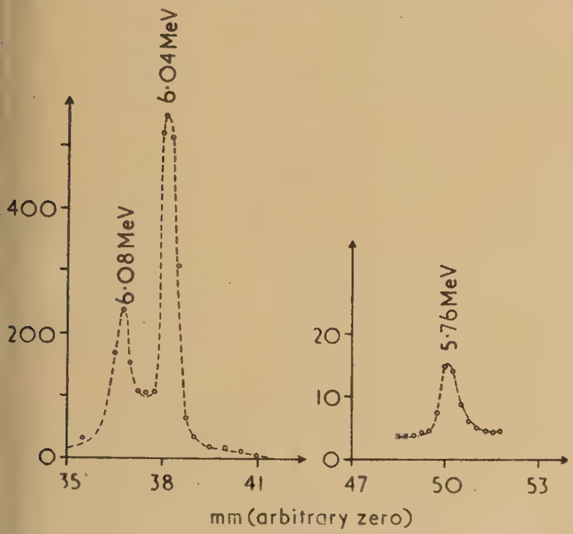
However, it is not in general possible to have the pla in the best position for focusing deuterons scattered fr elements at the same time. The best position of the is a compromise between the best positions of the compo which are required to be resolved. The authors have times reduced the angular aperture from 10° to 5° to min this effect. It is, in principle, possible to determine the nucleus by the condition of the focus. If the plate is that it is inclined to a line at right angles to the gap, diff parts of the focus trace are at varying distances from the and it should be possible to obtain a trace the sharpne which varies along its length, depending on the iso present in the target, in a manner characteristic of the nucleus responsible for the particular trace.

(*f*) *Source size and thickness.* The preceding disc suggests that it should not be difficult to reach or exc resolution of 1 in 1000 in momentum, but, in fact, size and thickness have proved to be the most serious f limiting resolution, up to the present. Line sources pendicular to the plane of the magnet gap, and of 0·25 mm or less, have been used; an 0·25 mm source an image 0·5 mm wide and hence an uncertainty in r of 0·22 mm or 0·11% in a radius of 20 cm; the uncert is, of course, greater if the source is not perfectly aline

The source thickness which can be used is limited b loss of energy of particles traversing different thicknesse the consequent inhomogeneity of the emergent par The authors have found that when the source is a bomb target, the effective thickness is liable to be much greater the actual one, unless great care is taken to ensure tha is flat. Even with natural α-particle sources, which can inciple be made very thin, some difficulty was found. es collected on thin wires, in order to limit their size been used, but the authors have been unable to prevent collection on the back of the wire; thus they have been tain of the exact effective thicknesses.

RESULTS

the first tests were made with α-particles from thorium deposit, collected on fine wires. The best plate-holder t was found by trial and error. Varying the angular ure and the mean value of θ was found to give the cted effects on resolution. The best results so far have obtained with a wire source 0·125 mm in diameter, n angular aperture of 10° about a mean angle θ of 50°. resolution obtained was 1 in 800 in momentum (1 in n energy) with a ratio of intensities of the line and the ground of 200 : 1. The separation of the 6·04 and MeV groups of α-particles, and the appearance of the bundant 5·76 MeV group above the background level r these conditions, are shown in Fig. 3. It is probable in this exposure, inhomogeneity of the field, error in the height, source size and source thickness (especially near op and bottom edges of the wire) made contributions of ar order to the line width.



g. 3. The resolution obtained with a radioactive source

posures have been made with the deuteron beam incident e plane of the magnet gap, at 26·2° from the horizontal, ransmission targets of Formvar, silicon monoxide and Resolution of 1 in 500 in momentum has been obtained, although the scattering angle is only 24°, groups of erons elastically scattered from nuclei of different mass eparated. An example of this is shown in Fig. 4. The ution is not as high as with natural α-particles and it is onsistent. This is thought to result from the wrinkling e targets under bombardment with consequent increase e effective thickness of parts of them. The effect was cularly noticeable with gold targets. It was found that eight of the plate for best focus varied as expected with mass of the target nucleus; for instance, deuterons ered from carbon were brought to focus at a point m lower than the focus for deuterons scattered from gold.

A fresh set of exposures was therefore made, with the beam entering the cylinder through a port at the side: with this arrangement, the angle between the incident beam and the beam accepted by the spectrometer is 70°, and reflexion targets may be used. With a target of about ¼ keV equivalent thickness of gold, evaporated on to a glass backing, a resolution of 1 in 800 in momentum has been obtained; the spectrum is shown in Fig. 5 where the width is seen to be hardly greater than that given by natural α-particles. The difference probably results from slightly greater contribution from the size and thickness of the gold target.

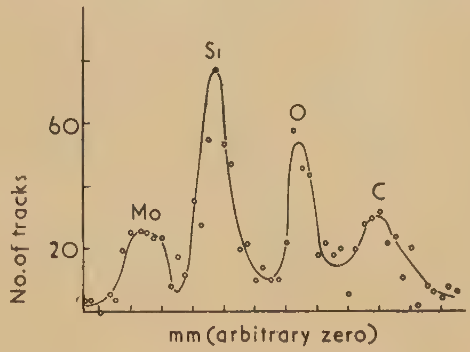


Fig. 4. Histogram of the density of tracks across the focus using a composite transmission target. Groups of deuterons elastically scattered from silicon, oxygen and carbon are clearly resolved. There is also present an impurity group from molybdenum

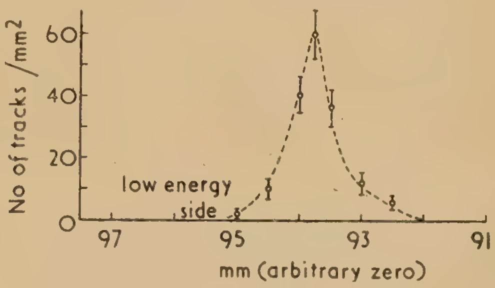


Fig. 5. Group obtained from a gold reflexion target. The resolution is about 1 in 800 in momentum

Exposure time, 1 min; estimated thickness, ¼ keV

CONCLUSIONS

It has been shown that a spectrometer of the type described can give resolutions up to 1 in 800 in momentum, and that under suitable conditions it should be capable of considerably better performance. It is hoped that future work will give improved resolution, and that the instrument will prove its usefulness in the study of nuclear reactions.

A larger version of this instrument, mounted on a turntable so that it can be rotated around a target, is now being built for the Associated Electrical Industries Research Laboratory.

ACKNOWLEDGEMENTS

We are very grateful to Profs. C. F. Powell and K. G. Emeleus for their continued encouragement, to Mr. P. H. Fowler for giving us the benefit of his original calculations, to Dr. H. Heitler for much of the design, to Mr. H. Ellacott for the constructional work, to Prof. W. E. Burcham for the loan of a radio-thorium source, and especially to Dr. T. E. Allibone and Mr. D. R. Chick for extending to us the hospitality and facilities of the Associated Electrical Industries Research Laboratory. We should also like to thank Dr. R. M. Payne, Mr. W. M. Jones, Mr. K. Firth and Mr. D. Hancock for all their assistance in arranging and making the exposure.

This work was carried out as part of a programme supported by the Department of Scientific and Industrial Research, to whom one of us (D. J. P.) expresses his thanks for a maintenance grant.

REFERENCES

(1) See, for example, Cockcroft. *J. Sci. Instrum.*, **10**, p. 71 (1933).
Stephens. *Phys. Rev.*, **45**, p. 1513 (1934).
Wadey. *Phys. Rev.*, **74**, p. 1846 (1948).
Snyder, Rubin, Fowler and Lauritsen. *Rev Instrum.*, **21**, p. 852 (1950).
Buechner, Van der Graaf, Strait, Stergiopoul Sperduto. *Phys. Rev.*, **74**, pp. 1226 and 1569 (
Collins, McKenzie and Ramm. *Proc. Roy. So* **216**, p. 219 (1953).

(2) Hafner, Donoghue and Snyder. *Phys. Rev.*, **75**, (1949), also private communication.

(3) Inglis. *Phys. Rev.*, **78**, p. 104 (1950).

(4) Gelinas and Hanna. *Phys. Rev.*, **89**, p. 483 (195

(5) Prowse. Ph.D. Thesis, University of Bristol (1954

A water vapour recorder for equatorial use

By C. G. Webb, B.Sc., A.Inst.P., and A. Rajaratnam, M.Sc., University of Malaya, Singapore

[*Paper first received* 3 *August, and in final form* 8 *November*, 1955]

A considerable extension of the range and accuracy of the thermocouple hygrometer is possible in an equatorial climate, owing to the small range of variation of atmospheric pressure and temperature. An instrument, with a linear range of water vapour pressure of 10–30 mm of mercury, has been designed for use in latitudes 0 ± 5°. Systematic departures from linearity were less than 0·2 mm on direct calibration. The use of a new reference temperature close to the mean air temperature is convenient, and with it a single check measurement suffices for standardization of the hygrometer.

Water vapour is an item of especial interest in the equatorial atmosphere. For its investigation a linear recorder of ample range has been designed by one of the authors, in a form similar to that used by the other.(1)

THEORY

Consider in the first place the range of dew points from 21 to 26° C, covering the daily outdoor range in Singapore (latitude 1° N). At a temperature θ the vapour pressure e is represented, to 0·5% or better, by $e = a\theta + b = 1{\cdot}300\,\theta - 8{\cdot}84$. If we assume Regnault's formula, and substitute this value of e', we have

$$\begin{aligned} e &= e' - AP(\theta - \theta') \\ &= a\theta' + b - AP(\theta - \theta') \\ &= a\left(\frac{E'}{k} + \theta_0\right) + b - \frac{AP}{k}(E - E') \\ &= \frac{a + AP}{k}\left(E' - \frac{AP}{a + AP}\cdot E\right) + (a\theta_0 + b) \\ &= X(E' - YE) + e_0 \qquad (1) \end{aligned}$$

say, where the dry and wet temperatures θ and θ' are considered to have been measured by thermocouples with e.m.f.'s $E = k(\theta - \theta_0)$, etc. Providing θ_0 is a reference temperature within the range of validity of the vapour pressure equation, e_0 is the corresponding saturated vapour pressure. It is a convenient fact that if θ_0 is also the mean air temperature, then e_0 is near the upper limit of the vapour pressure range. Further, in this case the measured quantity $(e - e_0)$ is, in the natural climate, rarely more than $e_0/4$, and averages much less, and errors in e due to inadequate air move and consequent variation in A are correspondingly red

Assuming the invariability of the psychrometric cons equation (1) can be utilized, as similar equations have by Sheppard and Elnesr(2) and Swinbank,(3) to me vapour pressures directly. The equation has already a u range and, owing to the relative constancy of equa temperature and barometric pressure, this range ca extended to 10 and 30 mm of mercury without troub noticeable departure from linearity. In extending the two types of error need to be considered: (i) non-lineari the vapour pressure scale due to the variation in a consequently in X; (ii) temperature errors due to a si change in Y.

(i) *Variation of X.* If X is evaluated over an exte range it is found to be a fairly linear function of the va pressure. Thus substituting $P = 757$ mm,(1) $A = 0{\cdot}00$ for gently ventilated thermojunctions,(4) $k = 41{\cdot}0\ \mu$V/° copper-contra thermocouples, and appropriate value $a = de/d\theta$, in the expression for X it appears that the rel

$$X = 0{\cdot}001\,32e' + 0{\cdot}0140$$

holds between $e = 10$ and $e = 30$ mm, with deviations than 0·5%. Now putting $\theta = \theta_0$ so that $E = 0$, for a change in vapour pressure we may write instead of equatio

$$d(e - e_0) = de = XdE_0'$$

where the introduction of the suffix indicates the insertio the temperature condition. Substituting for X

$$dE_0' = de/(0{\cdot}001\,32e' + 0{\cdot}0140)$$

The value of X incorporated in this equation is r precise but the equation is not very useful as it stands.

vever, in the climate under consideration $(\theta - \theta')$ exceeds 5° C, and the difference between e and e' is a common value being about 1 mm of mercury. The n X due to writing e for e' is appreciable (nearly 10%), ry much less than that due to using a fixed value of X extended range. If we accept the substitution of e for he enumerator above it is possible to proceed. The of a direct check calibration will later be offered in ation of this step.

grating, and inserting the further condition that, when $= \theta_0$, it follows that $E' = 0$ and $e = e_0$, we have

$$E_0' = 1744 \log \frac{0{\cdot}001\,32e + 0{\cdot}0140}{0{\cdot}001\,32e_0 + 0{\cdot}0140} \qquad (3)$$

erature compensation *via* the second term in equation (1) s equation (3) generally valid. Although this relation en E_0' and e is not quite linear, that between e and the ometer deflexion may be made so by suitably position- e scale or the recording camera. Thus if α and x are gular and linear deflexions, having values α_0 and x_0 and if also $(\alpha - \alpha_0) = qE_0'$ and the scale distance is d,

$$x - x_0 = d(\tan\alpha - \tan\alpha_0)$$
$$= d[\tan(\alpha_0 + qE_0') - \tan\alpha_0]$$

is not difficult to choose convenient values of q, α_0 which make $(x - x_0) = (e - e_0)$ and $x = e$ on any d scale.

Variation of Y. In the first place a single value,)·26, was adequate for the restricted range of e, but in tended scale that is no longer so, and the temperature endence of the vapour pressure reading depends on the diment in the thermocouple circuit of a value of Y priate to the actual vapour pressure.

emperature variation $\Delta\theta$, from the mean at θ_0, produces rious vapour pressure change approximately equal to θ. Of this an amount $X\Delta Yk\Delta\theta$ is in excess of that d for compensation of the effect of the temperature e on the wet junction, and gives rise to a temperature Δe in the measured vapour pressure. Temperature ions may be either the ordinary diurnal variation -year average at Singapore being ±2·5° C, with ±5° C common), or rapid fluctuations such as occur close to eated ground. The annual variation is small. Values , calculated for $\theta_0 = 27$ and $\Delta\theta = 5°$ C, are given in 1, e and Δe being in mm of mercury, and X in mm of ry per μV.

1. *The influence of a temperature increase of 5° C on the measured vapour pressure*

10	15	20	25	30
0·417	0·337	0·281	0·242	0·212
0·0273	0·0339	0·0405	0·0471	0·0537
+1·052	+0·751	+0·432	+0·126	−0·187

ight have been expected, no single setting of Y is ate for this extensive range of vapour pressures. For dinary diurnal range of vapour pressure of less than , such a setting can be found if errors of about 0·1 mm rcury are tolerated; and the provision of three or four gs would be adequate for most purposes though only or at most two, would be needed for use in any given nment.

thod of adjustment. The galvanometer reading on open should be set to e_0. Closing the circuit, the galvanometer series resistance should be adjusted until the vapour pressure reading agrees with that of a standard hygrometer, preferably in a closed chamber at a low humidity. It may be necessary to adjust Y, and repeat the last operation.

PRACTICAL DETAILS

The mean air temperature at Singapore is close to 27° C. Diphenyl ether, $(C_6H_5)_2O$, melting point (measured) and latent heat 26·65° C and 24·2 cal/g$^{(5)}$ respectively, is a stable, non-hygroscopic, fairly inoffensive and readily available substance which has been found suitable for the maintenance of the reference point. In a vacuum flask 300 cm^3 of this substance has been found to remain partly solid for a period of several weeks indoors. Substituting the corresponding $e_0 = 26{\cdot}15$ mm in equation (3), we have

$$E_0' = 1744 \log(0{\cdot}0272e + 0{\cdot}289) \qquad (4)$$

It was found possible by trial to make $x = e$ on a scale of 1 cm per mm of mercury by choosing $\alpha_0 = 40°$, $d = 38$ cm, for $q = \frac{1}{24}$. (See Table 2, in which e and Δe are measured in mm of mercury, E_0' in μV, α in degrees and x in cm.)

Table 2. *The linearity of the calculated vapour pressure scale*

e	10	15	20	25	30
E_0'	−438	−273	−138	−24	+75
α	21·8	28·6	34·2	39·0	43·1
$(x - x_0)$	− 16·64	− 11·09	− 5·98	− 1·06	+ 3·84
$(e - e_0)$	− 16·15	− 11·15	− 6·15	− 1·15	+ 3·85
Δe	+ 0·49	− 0·06	− 0·17	− 0·09	+ 0·01

Anticipating the necessity of a final empirical adjustment of α_0 this small value of Δe was ignored. The humidity mixing-ratio is similarly represented, if $d = 35$ cm.

The thermojunctions, *dj* and *wj* in Fig. 1, were designed to minimize the effects of conduction along the wires and

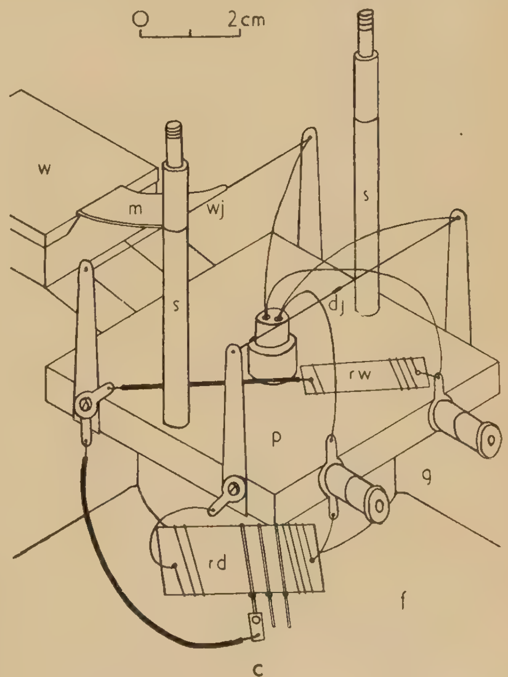


Fig. 1. Equatorial psychrometer head

wick, of radiation and of variation in the psychrometric constant. They were mounted on prongs rising from a Tufnol platform *p*, attached to the stopper of a half-pint vacuum flask *f*, containing diphenyl ether. The copper wire in each case was bare 40 s.w.g., soldered to the tapered end of a bared double-silk covered 36 s.w.g. contra wire. The exposed part of each wire was 2·5 cm long. The wet junction was kept moist by a strip of muslin *m* 1 cm wide, superficial density 0·0108 g/cm² and water content 0·0285 g/cm² when doubled over the junction. The distance from the wet junction to the reservoir *w* was 1·5 cm. The resistances of the thermocouples were adjusted to 5 Ω each, and they were shunted with 5 Ω resistors *rw* and *rd*, the latter being tapped at 1·3, 1·5 and 1·75 Ω to permit *Y* to be varied, as necessary, by moving the connexion *c*. A large double radiation shield of sheet aluminium provided for use out-of-doors supported by the pillars *s*. The axis of the shield was i meridian and allowed free air movement in that dire No improvement was observed when a triple shield was Another double shield was provided for the vacuum but later experiments showed that this was only mode effective. Also, to reduce the vertical temperature gra in the diphenyl ether, which was appreciable during extr of weather, an aluminium core, 2·5 cm in diameter, inserted in the flask. The galvanometer had a resistan 50 Ω, a period of 1·9 s, and was connected to the termi *via* a series resistance of 37 Ω, this value being determin checking against a dew point hygrometer at a vapour pre of 10·8 mm of mercury, with an air velocity of approxim 30 cm/s. The result of a direct calibration of the psy meter is shown in Fig. 2.

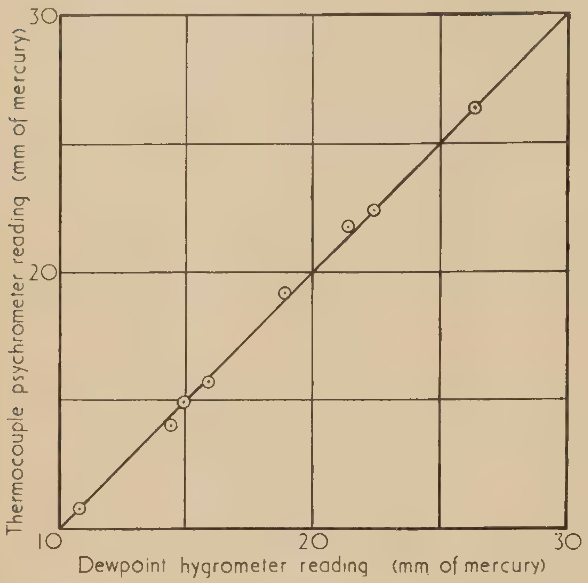


Fig. 2. Result of direct calibration of the psychrometer

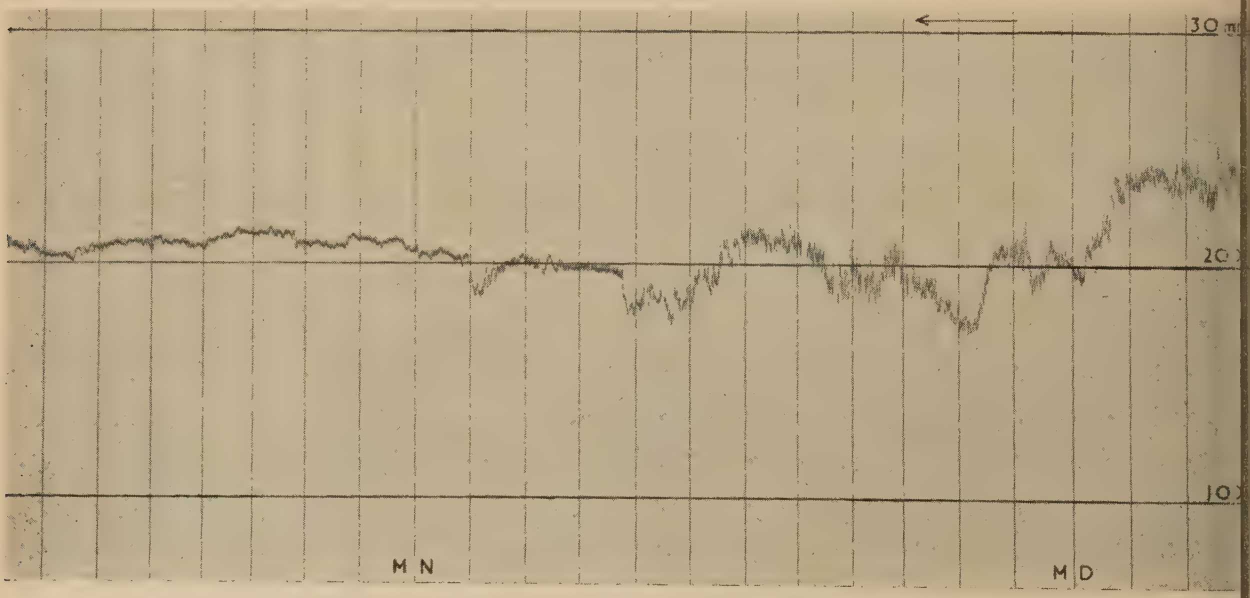


Fig. 3. Typical twenty-four-hour record of atmospheric water vapour pressure at Singapore

As a test of the dependence of the measured vapour pre on air velocity under working conditions, two similar similarly situated instruments were connected in oppo and one was provided with a blower. No significant diffe in the measured vapour pressure was observed over a p of five days, including clear hot weather. A typical tw four-hour record is reproduced in Fig. 3.

ACKNOWLEDGEMENTS

Thanks are due to Mr. Low Chiap Seng for his pra assistance.

REFERENCES

(1) RAJARATNAM, A. M.Sc. Thesis, University of Ma 1954.
(2) SHEPPARD, P. A., and ELNESR, M. K. *Quart. J. Meteorol. Soc.*, **77**, pp. 450–453 (1951).
(3) SWINBANK, W. C. *J. Sci. Instrum.*, **28**, pp. 86–89 (1
(4) MONTEITH, J. L. *Proc. Phys. Soc.* [*London*] *B*, **67**, pp. 226 (1954).
(5) FURUKAWA, G. T., GINNINGS, D. C., MCCOSKEY, F and NELSON R. A. *J. Res. Nat. Bur. Stand.*, pp. 195–206 (1951).

An automatic scanner for nuclear emulsions

By S. J. GOLDSACK, B.Sc., Ph.D. and H. B. VAN DER RAAY, M.Sc., Department of Physics,
University of Birmingham

[*Paper received* 10 *October*, 1955]

A photoelectric method of obtaining the angular distribution of tracks in nuclear emulsions is outlined. Details of the apparatus constructed and its performance are given. The angular resolution is about $\frac{1}{2}$° and the apparatus can be made to accept tracks of minimum grain density.

ear emulsions, widely used in cosmic-ray physics, are lly finding application in the field of high energy erators as particle detectors. Their special features : them suitable for use with machines such as the ingham synchrotron,(1,2) where the short pulse length es counter techniques difficult. The small physical size nulsions, combined with the fact that they are unaffected trong magnetic fields, makes it possible to place them near or actually within, the synchrotron's vacuum nber. A single emulsion will record not only the presence particle, but also its direction, and the track density gives ndication of the particle's energy.

though the presence of particles may be simply and ly recorded in nuclear emulsions, the extraction of the , after processing, is slow and tedious. When the lsion is used as a particle detector, the problem is often of obtaining an angular distribution of the tracks in the lsion. This may be done by visually scanning the emul- s and estimating the alinement of the tracks relative to hair line of a goniometer. An accuracy of 1° may be eved in this way. For greater accuracy it becomes ssary to move the tracks into coincidence with the hair Apart from the far greater time required, it becomes cult to ensure that the emulsion is reset to the correct tion after each measurement. Approximately one dred tracks per hour may be measured by the former nod and twenty to thirty by the latter. When good stics are required, the time for scanning becomes excessive.

these angular distributions could be obtained by some oelectric method, the comparatively short time required ld make many experiments using emulsions as particle ctors(3) more feasible. For instance, the circulating beam synchrotron may be scattered by an internal target and scattered particles, after being momentum analysed by existing magnetic field, detected by emulsions suitably ed within the vacuum chamber.(4) Thus a complete ular distribution of the scattered particles may be obtained one exposure, obviating the necessity of normalizing one ering angle with respect to another. The machine time ired is greatly reduced, which is often a worthwhile ideration. The small physical size of emulsions makes ossible to place them close to the scatterer, whilst main- ng good geometry. The increased intensities thus lable have obvious advantages.

hen using nuclear emulsions in conjunction with a otron, it is often desired to count the number of, for nce, short α-tracks, in a given area of the emulsion. may again be done more speedily with some photo- ric method.

consideration of these problems led to the design and truction of the instrument described in this paper, which speedily determine the angular distribution of tracks in ven emulsion. The instrument may also be used to record number of short tracks in a given area of the emulsion.

PRINCIPLE OF OPERATION

If a slit is placed in the image plane of a microscope, the reduction in light intensity occurring when a track lies under it, may be detected by a photomultiplier. After suitable amplification, this pulse may be used to trigger an amplitude discriminator and then be recorded on a scaler. Since in most experiments it is desired to count tracks of minimum ionization in the presence of a background of heavier tracks, this simple system will not be adequate. A heavy track slightly misalined will produce a signal equal to that of an accurately alined minimum track and would thus be recorded as such.

To overcome this difficulty the slit is divided into two halves and coincidence is taken between the signals obtained from separate photomultipliers viewing each half of the slit. As the plate is scanned by moving the microscope stage by some mechanical means, all the tracks parallel to the slit are recorded. The plate is now rotated through the required angle and scanned again. In this way a complete angular distribution of the tracks in the plate is obtained.

By adjusting the discriminator bias level, tracks of varying density may be recorded. With a simple discriminator all track densities from black to some fixed minimum are recorded; by plotting a bias curve the various track densities may be separated. Alternatively, a differential pulse height analyser may be used and the apparatus set for the required track density only. The two-slit coincidence system is illustrated schematically in Fig. 1.

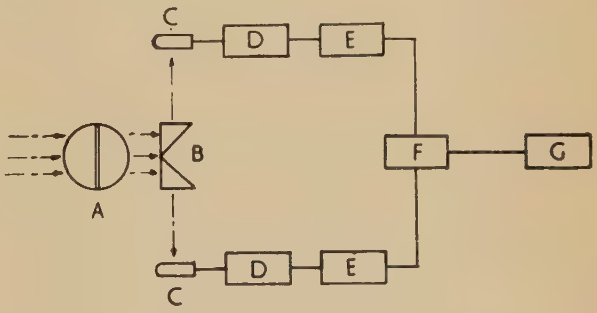


Fig. 1. Block diagram of scanning system

A, slit; *B*, prisms; *C*, photomultiplier; *D*, amplifier; *E*, discriminator; *F*, coincidence unit; *G*, scaler.

DESCRIPTION OF APPARATUS

(*a*) *Optics.* The optical system utilizes a type 4000 microscope (by Cooke, Troughton and Simms Ltd.) using a ×45 oil immersion objective and a standard 35 mm camera attachment for projecting the image on to the plane of the slit. Each half of the slit is 16 mm long, corresponding to

80 µ in the emulsion. The width is adjusted to slightly less than that of the track in the image plane. This condition gives optimum signal height. The light emerging from the slit is divided by two 45° prisms and detected by two type 931A nine-stage photomultipliers (by the Radio Corporation of America). In order to improve the light transmission, it was found necessary to have a thin layer of oil between the microscope condenser and the glass backing of the emulsion.

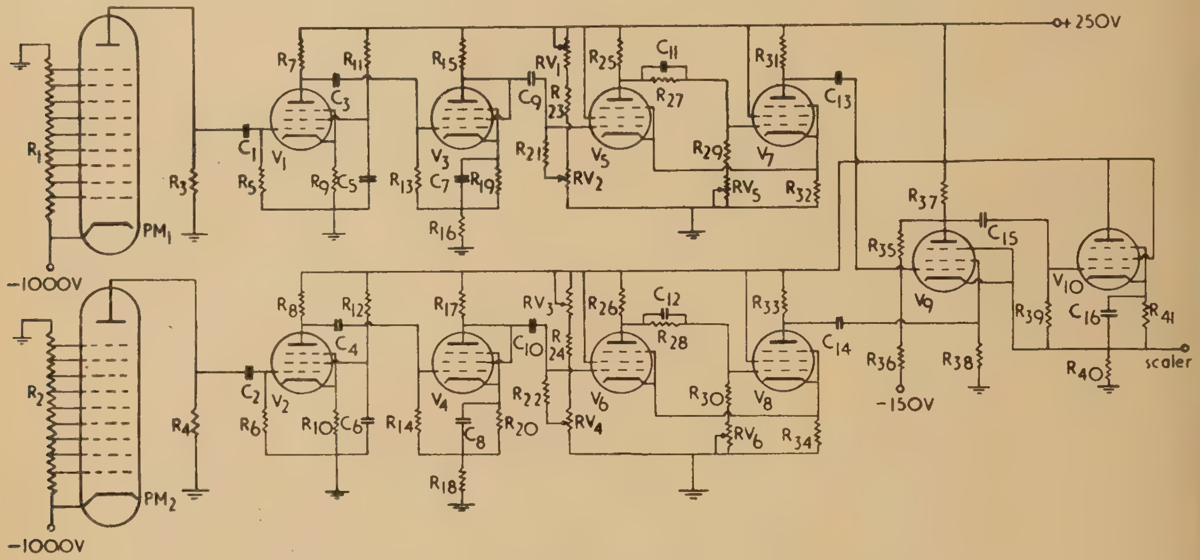


Fig. 2. Circuit diagram of two-slit coincidence system

R_1, R_2 = 1 MΩ
R_3, R_4 = 2 MΩ
R_5, R_6 = 1 MΩ
R_7, R_8 = 4·7 kΩ
R_9, R_{10} = 620 Ω
R_{11}, R_{12} = 10 kΩ
R_{13}, R_{14} = 100 kΩ
R_{15} = 22 kΩ
R_{16} = 10 kΩ
R_{17} = 22 kΩ
R_{18} = 10 kΩ
R_{19}, R_{20} = 200 Ω

R_{21}, R_{22} = 1 MΩ
R_{23}, R_{24} = 75 kΩ
R_{25}, R_{26} = 3·9 kΩ
R_{27}, R_{28} = 100 kΩ
R_{29}, R_{30} = 39 kΩ
R_{31} = 5 kΩ
R_{32} = 10 kΩ
R_{33} = 5 kΩ
R_{34} = 10 kΩ
R_{35} = 270 kΩ
R_{36} = 130 kΩ
R_{37} = 4·7 kΩ

R_{38} = 39 kΩ
R_{39} = 100 kΩ
R_{40} = 10 kΩ
R_{41} = 1·7 kΩ

RV_1 = 47 kΩ
RV_2 = 50 kΩ
RV_3 = 47 kΩ
RV_4 = 50 kΩ
RV_5, RV_6 = 22 kΩ

C_1–C_4 = 0·1 µF
C_5–C_8 = 0·5 µF
C_9, C_{10} = 0·1 µF
C_{11}, C_{12} = 30 pF
C_{13}–C_{15} = 0·1 µF
C_{15} = 0·5 µF

V_1, V_2 = 6CH6
V_3–V_{10} = EF91

PM_1, PM_2 = 931–A

The illumination is obtained from a standard 48 W multi-filament bulb supplied by a 6 V accumulator. The system is sensitive to slight changes in intensity of the light source, and will count the 50 c/s ripple if an a.c. supply is used. The use of an accumulator, frequently re-charged, ensures a constant light source. The photomultipliers are supplied from a regulated high-tension supply and the whole system is perfectly stable.

(*b*) *Electronics*. The signals obtained from the photomultipliers are fed to an amplifier, thence through an amplitude discriminator to a coincidence unit and scaler where they are recorded. The circuit diagram is shown in Fig. 2. The amplifiers require to be of only limited band width, as the pulse lengths encountered during normal scanning are of the order of a millisecond. The long duration of the pulses and the comparatively slow counting rate, of the order of ten per second, leads to a simple design for the discriminators and coincidence circuits. The system shown has been successfully tested with 0·5 µs pulses at a repetition rate of 5000 per second.

(*c*) *Mechanical drive*. The microscope stage has to be moved at a constant velocity, as the area of the plate is scanned. It is then returned to its initial position, to be scanned again at a different angle. A direct mechanical drive results in considerable vibration, with the possibility of a given track being counted more than once. The revers
the system at the end of each traverse, without apprec
loss of time, can most effectively be achieved by the use
cam.

Consideration of these facts lead to the adoption of a
operated hydraulic system. This ensures a smooth vibra
less drive, with adequate damping at the end of each s
to prevent stress on the stage. Moreover, there ar
vertical forces which would tend to move the plate ou
focus. The system is shown diagrammatically in Fig. 3.
the purpose of testing, the cam is driven by a d.c. m
separately excited, thus giving a wide speed range.
motor will be finally replaced by a fractional horse p
induction motor, which, owing to the small load, will ru
a constant speed.

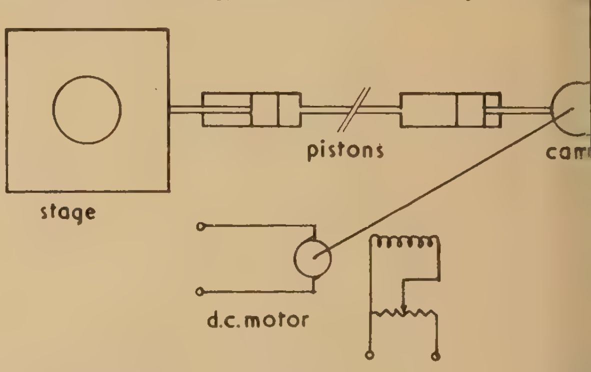
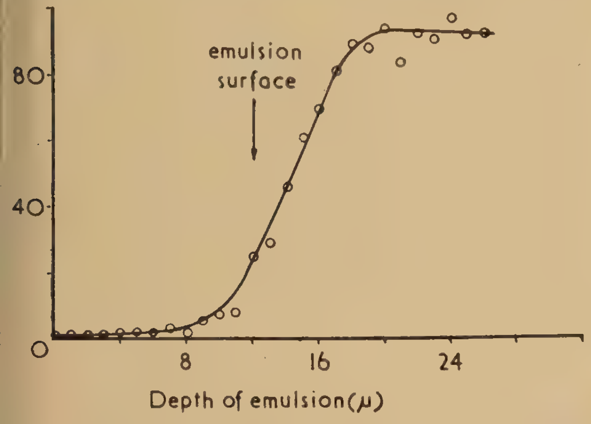


Fig. 3. Block diagram of hydraulic drive for movi
microscope stage

PERFORMANCE

the system is to work, the signal obtained from an d minimum track must be well above background, so a definite trigger is available for the discriminator. The m shown delivers a 30 V signal for a minimum track, n is alined for coincidence. This is well above back- nd noise due to dirt in the emulsion, out-of-focus tracks tracks which are misalined. It is further an order of iitude greater than tube shot noise.

e effective depth of focus was determined by scanning a plate set at a fixed angle and varying the fine focus of nicroscope. The curve obtained from the surface of the sion, determined visually, is shown in Fig. 4. From this it may be concluded that the effective depth of focus is t 14 μ. This corresponds to an emulsion thickness, e processing, of about 30 μ. Thus 50 μ emulsions are suitable for use with the automatic scanner. These are and quickly developed without the elaborate pre- ons necessary in processing thicker emulsions. Thicker sions could be scanned at various depths, successive s being suitably separated to prevent recording the same s more than once. However, a 200 μ emulsion, when ned through its entire depth, was found to give a lower iting rate towards the bottom of the emulsion. This was ably due to development gradient usually encountered thicker emulsions.



g. 4. Variation of counting rate with depth of emulsion

density of tracks of approximately 5×10^5 per cm^2 ars to be satisfactory for counting, giving a reasonable ber of tracks per traverse, whilst being low enough for lental coincidences to be negligible. In order to improve stics, 50 μ stripped emulsions may be used, having all advantages of the thicker emulsions yet none of their lvantages. The signal-to-noise ratio for 50 μ emulsions etter than that for thicker emulsions since the effective h of focus for dirt and heavier background tracks is ter than that for the desired tracks.

varying the speed of traverse, it was found that the ber of tracks recorded decreased at the higher speeds, the iting rate falling by a factor of two for a speed change 0·2 to 0·5 cm/s. A possible explanation of this may reduction in the optical quality of the tracks, due to the ring of the oil on the objective causing some cavitation. nge of speeds below 0·2 cm/s was found over which the iting rate remained constant. A speed corresponding to ne of traverse of 15 s was adopted for all measurements. length of traverse was fixed at 2 cm.

Consistency of counting was determined from thirty successive traverses of the same tracks. A variation of less than the standard deviation of a Poisson distribution was found. Due to the continued back and forth motion of the stage, it might be expected that the tracks would move out of focus. However, after continual scanning for a further fifteen minutes, the number of tracks recorded still agreed with that previously obtained.

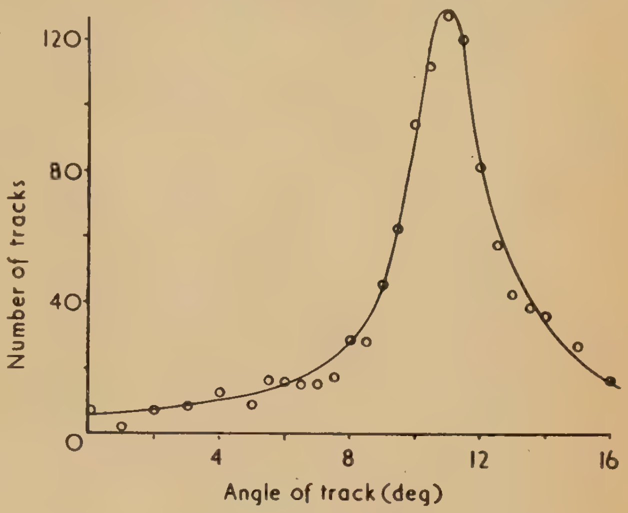


Fig. 5. Angular distribution of minimum tracks

Fig. 5 shows the angular distribution obtained by scanning an emulsion placed in a beam of protons scattered out of the synchrotron and collimated by a channel of 1 cm^2 section and 20 cm long. A photograph of a typical field of view is shown in Fig. 6. As this distribution falls to nearly zero, it is clear that misalined tracks, although numerous, are not recorded. The angular resolution could not be determined since the spread in the beam is appreciable; however, from this result and that quoted below, it is estimated to be better than $\frac{1}{2}$°.

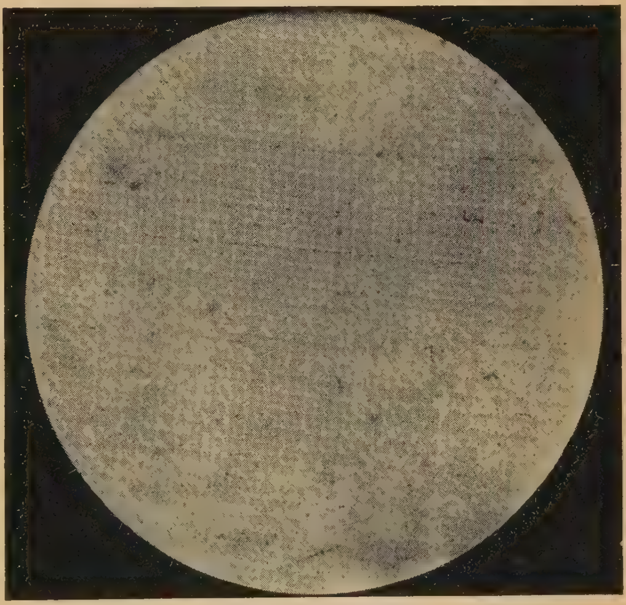


Fig. 6. Typical field of view

The angular resolution may, if necessary, be improved by differentiating the outputs of the two discriminators. The two pulses must then arrive within a time *t* of each other, determined by the time constant of the differentiating circuit. This does however, make the angular resolution dependent on the velocity of scanning. As it is proposed always to scan at the same constant rate, this poses no problem.

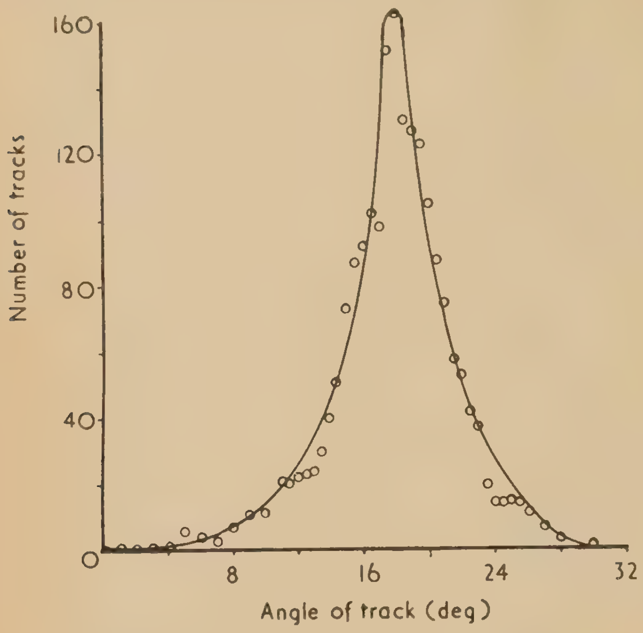


Fig. 7. Angular distribution of nitrogen tracks

In many experiments it will be necessary to count min tracks in the presence of heavier ones. With this in an emulsion was scanned containing nitrogen tracks obt from the Birmingham cyclotron. The distribution obt is illustrated in Fig. 7. It is evident that even black t when at the wrong angle, will not be recorded. Th criminator setting was the same as that used in obtainin previous distribution.

Clearly then, accurate angular distributions may be obt from emulsions containing both minimum and black t Both distributions shown were obtained in less than t minutes, whereas if determined visually, to an accura 1°, approximately eight hours would have been required

ACKNOWLEDGEMENTS

We wish to express our thanks to Prof. P. B. Mo whose suggestion this work was carried out. One (H. B. v. d. R.) wishes to express his gratitude to the Univ of Birmingham for a grant whilst undertaking this work

REFERENCES

(1) Moon, P. B., Riddiford, L., and Symonds, J. L. *Roy. Soc.*, **230**, p. 204 (1955).

(2) Riddiford, L., van der Raay, H. B., and Coe, *Proc. Phys. Soc.* [*London*], **68**, p. 489 (1955).

(3) Towler, O. A. *Phys. Rev.*, **85**, p. 1024 (1952).

(4) Anderson, D. L., and van der Raay, H. B. Re Liverpool Conference July, 1955. [See *Nature* (*Lon* **176**, p. 371 (1955).]

A versatile X-ray diffractometer for single-crystal and powder studies

By A. R. Lang, M.Sc., Ph.D., A.Inst.P.,* Cavendish Laboratory, University of Cambridge

[*Paper first received* 5 *October, and in final form* 7 *December*, 1955]

A robustly constructed instrument is described which can be adapted to a wide variety of diffraction techniques. Specimen axis and counter arm are independently rotatable, manually or automatically, and are both carried by opposed tapered roller bearings. Following a predetermined programme, spectrum scanning may be performed at two speeds: slowly at angles of interest, and fast elsewhere. Graphical recorder indication of diffracted intensity can be made independent of X-ray output fluctuations by using a potentiometer reference voltage proportional to X-ray tube current.

The machine⁽¹⁾ described in this paper was designed to serve as a general purpose diffraction instrument which would fill some of the needs of an X-ray diffraction laboratory engaged on a wide variety of studies. The specimens (single crystal or polycrystalline) and the detectors which have been employed (film, and Geiger, proportional and scintillation counters) may be changed in a few minutes by virtue of the ready adjustability and removability of a number of components of the instrument. Operating methods may range from independent manual control of specimen angle and counter angle, to fully automatic spectrum scanning according to a predetermined programme punched on a strip.

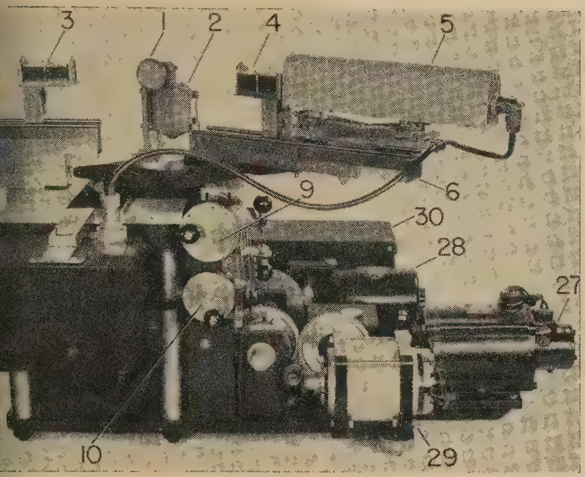
The basic aims of the mechanical design were to achieve adequate accuracy while making minimum demands on machining operations. To keep costs low, war surplus components were incorporated wherever possible; most moving parts were, in fact, of this nature. The robus enables all moving parts to sustain loads greatly in e of normal requirements so that the amount of addit equipment that might be attached to the instrument in sp experiments need not be limited.

In single crystal studies, and in special studies with crystalline specimens, such as preferred orientation d mination, it is necessary to vary independently the an settings of specimen and counter. For this reason specimen axis and counter arm axis are provided with sep precision worm drives and angle-indicating means, cou of the worms to give the 2 : 1 ratio of rotation speeds optional. For powder work an X-ray tube line focus pa to the diffractometer axis, rather than an illuminated functions as the source of divergent X-rays required. arrangement was recognized as essential to give the nece resolution and intensity. Aberrations due to ve divergence are reduced by Soller slits. When the X-ray is itself the source, it is desirable that it should be well-ed and free from a large "penumbra." To achieve this ition, the X-ray tube cathode assembly was modified to a sharply bounded focus not more than 1 mm wide.(2)

---

* Now at Harvard University, Massachusetts, U.S.A.

MECHANICAL DESIGN



g. 1. Diffractometer arranged for reflexion powder-specimens

Fig. 1 is shown a side view of the diffractometer set up the standard Brentano reflexion powder-specimen iique. Specimen material, usually mixed with some er, is loaded into a well in a disk-shaped specimen er (1) which is rotated in its own plane by the motor (2) d.c. ex-R.A.F.). The window of the horizontally nted X-ray tube (not shown in Fig. 1) is placed up ist the entry slit assembly (3); X-rays pass first through rizontal-divergence limiting slit, then a pack of Soller to limit vertical divergence, and then an anti-scatter slit. receiving-slit assembly (4) is similar to the entry slit nbly; it contains an anti-scatter slit, a pack of Soller and a receiving slit. Behind the last named is placed letector; in the arrangement shown in Fig. 1 this is an window Geiger–Müller tube contained in an earthed ing (5). The collimator block which supports assembly and the counter arm which supports assembly (4) and ter housing (5), are both topped by smooth parallel rods ing optical ways. Items (3), (4) and (5), and a variety her components, can be clamped to the ways in any ed position as indicated by steel millimetre scales attached gside the rods. It can be seen that the counter arm is ed into two sections: the section (6) further from the actometer axis may be removed if required. The top (7) of the diffractometer frame is flat-ground to form ference surface on which ancillary equipment may be nted. The collimator block (8) is precisely positioned on (7) by dowel pins; it can be detached simply by loosening bolts. The cable issuing from the counter housing to an A.E.R.E. probe unit type 1014 A which is sus- ed from a bracket clamped to plate (7). The hand- ls (9) and (10) permit manual turning of the counter arm specimen axis, respectively. The worm wheels have 360 and so with single-start worms one revolution of the wheel rotates the specimen axis (or counter arm) by one e. The handwheel drums are divided to read minutes c. Settings to 0·1–0·2 minute of arc may be made by eye-estimation without difficulty. Geared to the worm shafts are easily-readable counters indicating degrees and tenths of degrees. The knobs seen to the right of the handwheels are attached to levers operating the dog-clutches (war surplus) which engage the automatic drive.

The heart of the diffractometer is the bearing system. As a fundamental principle of design it is desirable to keep friction as low as possible. Traditionally, cone bearings of small taper angle have been used in accurate spectrometers, but these are not suitable for continuous motion with large unbalanced moments. Various combinations of ball bearings, angular contact and thrust, have been reported in designs of optical and ionization spectrometers aiming at reduced friction. But for sustaining large off-axial loads tapered roller bearings are to be preferred. Hence it was decided to carry both specimen shaft and counter arm in a system of concentric opposed tapered roller bearings, in an arrangement believed to be novel so far as application to spectrometer design is concerned.*

Fig. 2 shows the bearing system in section. All types of specimen mount are attached to caps of the form shown at (11) which fit upon the table (12) terminating the central specimen shaft (13). The specimen shaft is carried by the bearings (14) housed inside the cylinder (15). The cylinder (15) is in turn carried by the bearings (16) which are housed in the casing (17) attached to the frame of the instrument. The flange at the top of cylinder (15) carries the counter-arm worm wheel (18) and also the counter arm. The base of the counter arm is in the form of a ring (19) which is located on (15) by pins and secured by three screws so that it can be readily detached if required. The specimen shaft (13) is turned by the worm wheel (20). These worm wheels are of gun-metal, six inches in diameter, and were derived from two war surplus gun-layer's telescope mountings. In the plan view, Fig. 3, the bearings of the counter-arm worm (21) are shown. [The specimen-axis worm (22) is mounted identically.]

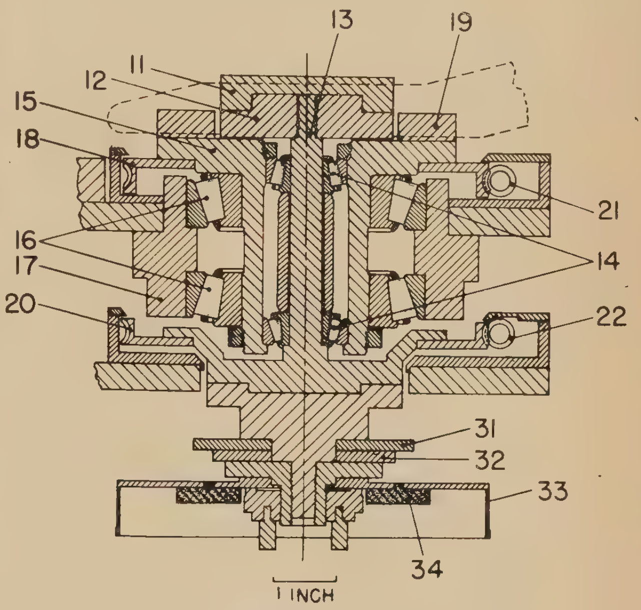


Fig. 2. Section of bearing system

---

* A similar bearing system, applied to an X-ray wavelength spectrometer, has been described recently by H. R. Moore, *J. Sci. Instrum.*, **32**, p. 324 (1955). However, the author's diffractometer was constructed in 1949.

It was decided to use a backlash-free type of spring-loaded bearing. To keep friction to a minimum and to obviate machining operations, a self-alining bearing (23) is used instead of the usual anti-backlash ball. The bearing (23) is subjected to a constant axial load by the spring-loaded ball (24). Tests of about fifty self-alining bearings mounted under such conditions showed that some gave a smooth rotation free from any detectable axial motion. Two such selected bearings were used. The other end of the worm shaft is supported by a ball bearing (25), the housing of which can move in a horizontal slide. A small leaf spring bears upon this housing and maintains the required pressure of the worm against the worm wheel. This pressure can be adjusted by the screw (26). The combination of ball bearings for the worm shafts and roller bearings for the worm-wheel shafts formed a very satisfactory friction-free arrangement.

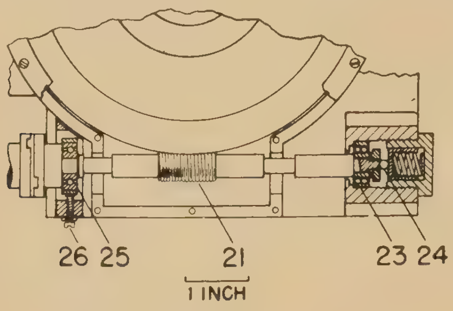


Fig. 3. Mounting of worm shafts

Precise measurements of diffraction line position and intensity require slow scanning across the lines. In the case of a simple spectrum at least a ten-fold reduction of experiment time can be achieved by means of a two-speed drive which will turn the counter arm quickly through the regions between lines. The two-speed drive adopted consists of independent fast and slow drives which are added by a differential. The slow drive operates continuously whilst the fast drive is intermittent. The fast motor drives the counter arm at about 20° 2θ per minute and is useful for setting the counter arm and specimen axis in any required position. It is even possible, when using wide slits, to pick up strong diffraction lines at this speed and so to make an ultra-rapid qualitative analysis of a specimen. Another feature of the design is that the slow-drive motor and speed-changing gearbox are quite independent of the diffractometer. They are mounted on a chassis placed some distance away in a Post Office rack. This arrangement not only reduces the bulk and weight of the diffractometer but also removes a source of noise and vibration. The motor unit and the diffractometer are linked by Selsyn motors, one of which is seen at (27), Fig. 1. It is connected to the differential through a 2000 : 1 enclosed double-reduction worm gearing. The reversible fast motor is seen at (28). The resultant diffractometer motion is communicated to the magslip (29) which is used for remote angle indication in the printing unit.(3) The motor unit contains a reversible synchronous motor of $\frac{1}{30}$ h.p. which drives the speed-changing gearbox through a magnetic clutch. The range of speeds available is 1°, $\frac{1}{2}$°, $\frac{1}{4}$°, $\frac{1}{10}$° and $\frac{1}{20}$° 2θ per minute. The motor unit carries all necessary spectrometer controls; however, these are duplicated on the control box (30) which contains a bank of relays. Attached to the rings (31) and (32), (Fig. 2), which can be set at any desired angle, are arms which operate limit switches during scanning of powder patterns. Since they are attached to the specimen shaft they can also be used when oscillating si
crystal specimens through small angles. The two-s
control, using a punched strip of 16 mm cinematograph
is similar in principle to that of the Wooster and M
spectrometer.(4) The strip is wrapped around the drum
which carries an angular scale. The insulating ring
isolates the drum electrically. Feelers bear upon the
and upon the lower rim of the drum. When a slot c
under the upper feeler a low voltage relay-operating ci
is made and the fast motor is switched off.

Angular calibration of both specimen and counter
angle indications have been performed, using an op
method. In the case of the counter-arm axis a roughly c
error was found which reached a maximum at $2\theta =$
(2θ reckoned clockwise, looking from above), with a
of 2·1′. In the range $2\theta = 0$–180°, the maximum e
at $2\theta = 180°$, was 1·8′. In this range the maximum rel
error in interplanar spacing, $\Delta d/d$, corresponding to the
in indicated angle, occurred at about $2\theta = 90°$, and poss
a value of about 1×10^{-4}. The value of $\Delta d/d$ vanishe
course, at $2\theta = 180°$. The most likely causes of erro
eccentricity of the worm wheel and improper mounting c
tapered roller bearings. An eccentricity error could e
have been introduced during the parting-off of the worm w
from its original bearings and its subsequent remoun
Some defects in the machining of the seatings of the bea
casings are known to exist.

In the case of tests on the specimen axis no signif
error could be detected, and so it was concluded that
axis was true to within a small fraction of a minute of a

ACCESSORIES

Several specimen mounts are available besides the rota
powder-specimen mount seen in Fig. 1. A mount for tr
mission specimens, permitting rotation of the specimen i
own plane, has been described elsewhere.(5)

Three adjustable bilateral slits are available, one of w
is of especially compact design and is used as a counter
on the diffracted-beam monochromator.(6) For routine w
it was found more convenient to use interchangeable f
slits fitting into the slit supports (3) and (4) of Fig. 1. A
tures of these range from 0·002 to 0·15 in. Slits
apertures of 0·002 to 0·006 in. have jaws of tantalum s
0·01 in. thick. Wider slits have lead jaws. Soller slits gi
vertical divergences of 2·3° and 7° may be used, or they
be removed entirely. The Soller slit partitions are of ro
tungsten 2 × 1 × 0·002 in. The surfaces of the partit
were found to be slightly rippled, and photographic f
placed in the position of the receiving slit showed that t
reflexion from those ripples was causing an effective broad
ing of the diffraction lines. A simple way of obviating s
impairment of resolution is to place the fine scanning
nearer to the specimen, and to use the position after
Soller slits for the anti-scatter slit.

The standard mount for Geiger counters is shown at
in Fig. 1. It has a spring-loaded "deck-chair" motion
independent elevation of front and rear. Independent s
to-side adjustment is also available at both front and r
The mounting arrangements for scintillation and proportio
counters(7,8) were more complex since these counters w
attached directly to their head-amplifiers.

Both incident-beam and diffracted-beam monochroma
are available. The former is attached to the front of
collimator block (8) and has accurate translational
angular adjustments. The latter(6) rides upon the cou

and has a scale and tangent screws for precise angular ng of the crystal and the counter-carrying bracket. Also ntable on the counter arm is the multiple slit system used ne focusing transmission-specimen technique.(5)

RECORDING METHODS

wo automatic recording systems are available: a scaling and printing unit(3) for digital point-by-point measure-ts, and a linear ratemeter and graphical recorder for tinuous registration of diffracted intensity. The scaler and meter are fed either from the Geiger counter probe unit, during proportional counting, from the single-channel se analyser. The scaler was a modification of the A.E.R.E. e 200,(9) and the ratemeter was based on the excellent ign of Cooke-Yarborough and Pulsford.(10) The recorder economically constructed with the aid of Meccano, xion and a war surplus Velodyne type 74.(11) It presented early-written 12 in. wide ink trace, and possessed adequate sitivity and response speed for diffractometer applications. the diffractometer counter-arm worm shaft is a wheel und which one to twelve pins can be fitted, corresponding angular intervals of 1° to 5′ of arc 2θ. These pins close tacts which actuate an angle marker on the graphical order and/or operate the printing unit.

COMPENSATION FOR X-RAY TUBE OUTPUT FLUCTUATIONS

A central problem in X-ray diffractometry is X-ray source bility. A simple circuit was developed to make the order indications independent of X-ray tube-current ctuations and it proved most effective. In this system the erence voltage in the self-balancing potentiometer of the order was made proportional to the X-ray tube current. resistance of 10 kΩ was inserted in series with the X-ray be-current milliammeter. Actually, two 20 kΩ resistances parallel were used so that no damage would occur if one them became open-circuited. As a further safety pre-ution, the X-ray generator was fitted with a small spark p to prevent excessive voltages appearing at the low-voltage d of the high tension transformer secondary. The resis-nces were connected to an external circuit, termed the mpensator unit, where by means of a range control switch ey could be put in parallel with a selection of high stability sistances. Permanently in parallel with them were two on tubes, normally non-conducting, but able to carry nsient discharges in the X-ray tube. The voltage appearing ross this resistance combination was passed through a nple resistance-capacitance filter of low time-constant, and en to a second variable, resistance-capacitance filter section. the latter, push-button switches could bring various pacitors into the circuit so that the time constant could be atched to the time constant of the ratemeter. By this means was possible to compensate not only slow drifts of the ains voltage supply but also abrupt changes caused by cal variations in load.

Now X-ray output is not only directly proportional to X-ray be current but is also a function of tube voltage. Provided me simple conditions are fulfilled in the circuit of the X-ray nerator, indications of the recorder can be made independent changes in both tube kilovoltage and current caused by ctuations of supply voltage. The relation between filament nission current I and mains supply voltage E can be repre-nted by a power series in E, but as an approximation it is fficient to use a single term only and write $I = aE^m$, where is about 5 or 6 and a is a constant. The intensity of characteristic X-rays emitted, X, is proportional to $I(V - V_0)^n$ where V_0 is the excitation voltage and n is often taken to be about 1·5. For the purposes of the present elementary calculations, I will be assumed to be the mean current and V the peak kilovoltage. Now $V = bE - cRI$, where b is related to the step-up ratio of the high tension transformer and its controlling autotransformer, R is the effective resistance of the high tension circuit, and c is the ratio of maximum current to mean current. If the compensator is operating successfully, the quantity X/I must remain constant. Denote this quotient by Z, in arbitrary units, then $Z = (bE - acRE^m - V_0)^n$ and $dZ/dE = n\ (b - macRE^{m-1})$ $(bE - acRE^m - V_0)^{n-1}$. Hence the proper operating conditions are $b = macREm^{-1}$, i.e. $bE = mcRI$, or $V = (m - 1)\ cRI$. Thus with the X-ray tube operated at 50 kVp and 12 mA, and taking m equal to 6, cR should be 833 kΩ. With a self-rectified tube, c will have a value somewhat over 2, so R should be about 400 kΩ. The actual measured resistance of the secondary of the high tension transformer was only about 100 kΩ. However, there was considerable resistance in the autotransformer circuit, and since 1 Ω in the primary high tension circuit is equivalent to r^2 Ω in the secondary, r being the transformer ratio, the effective resistance was probably of the right order of magnitude. Tests showed that with the above values of kilovoltage and tube-current, the correct operating conditions must have been closely approached. When these conditions are satisfied, changes of ±5% and ±10% in mains supply voltage produce calculated falls of only 1% and 5 or 6% in Z, respectively. A drop of more than 10% was artificially introduced into the supply voltage, causing the indicated tube current to fall from 12 to 5 mA. The fall observed in recorder indication was only 2%.

ACKNOWLEDGEMENTS

The diffractometer was constructed in the Cambridge University Engineering Laboratory under the supervision of Mr. J. H. Brookes and Mr. A. A. Barker, whose willing co-operation is gratefully acknowledged. The machining was done by Mr. V. Clayden. Thanks are also due to Mr. J. Fuller of the Cavendish Main Workshop and Mr. C. Chapman of the Crystallographic Department Workshop, who supervised the construction of most of the accessories. The author wishes to thank Prof. Sir Lawrence Bragg and Dr. W. H. Taylor for their interest and encouragement during the course of the work. Financial support was provided by the British Electrical and Allied Industries Research Association and is acknowledged with gratitude.

REFERENCES

(1) Lang, A. R. Ph.D. Thesis, University of Cambridge, 1952.

(2) Lang, A. R., and Broad, D. A. G. *Brit. J. Appl. Phys.* To be published.

(3) Lang, A. R. *J. Sci. Instrum.*, **29**, p. 176 (1952).

(4) Wooster, W. A., and Martin, A. J. P. *Proc. Roy. Soc. A*, **155**, p. 150 (1936).

(5) Lang, A. R. *Rev. Sci. Instrum.*, **26**, p. 680 (1955).

(6) Lang, A. R. *Rev. Sci. Instrum.*, **27**, p. 17 (1956).

(7) Lang, A. R. *Nature* [*London*], **168**, p. 907 (1951).

(8) Lang, A. R. *J. Sci. Instrum.*, **33**, p. 96 (1956).

(9) Rotblat, J., Sayle, E. A., and Thomas, D. G. A. *J. Sci. Instrum.*, **25**, p. 33 (1948).

(10) Cooke-Yarborough, E. H., and Pulsford, E. W. *J. Instn Elect. Engrs*, **98** (II), p. 191 (1951).

(11) Williams, F. C., and Uttley, A. M. *J. Instn Elect. Engrs*, **93** (IIIA), p. 1256 (1948).

Application of the electrostatic precipitator to the measurement radioactive aerosols

By B. A. Bergstedt, Civ. ing.,AB Atomenergi, Department of Physics, Stockholm, Sweden

[*Paper first received* 7 *October, and in final form* 12 *December*, 1955]

A continuous air monitor and a portable dust sampler are described both using a new type of electrostatic precipitator. In the continuous air monitor the dust is collected on a moving aluminium tape which then passes the radiation detectors. The precipitator is operated at very low efficiency, giving a high sensitivity which is nearly independent of air flow rate. The effective drift velocity of the particles towards the collection surface is more than ten times that in the Cottrell-type precipitator.

This paper describes a continuous air monitor and a portable dust sampler, both using a new type of electrostatic precipitator. The instruments are used for health physics measurements of radioactive aerosols. The continuous air monitor is of the time delay type first described by Kuper, Foster and Bernstein,$^{(1)}$ in which the radioactive dust is collected on a moving tape which then passes the radiation detectors. This system is suitable for monitoring the level of long-lived airborne activity, when a time delay is necessary for the short-lived activity (mainly from radon products) to decay before the activity measurement is made. Application of the electrostatic precipitator to the moving tape system has been made by Wilkening$^{(2)}$ and to the radioactive dust sampler by Carmichael and Tunnicliffe$^{(3)}$ and others. The general properties of radioactive aerosols and their health physical significance will not be discussed here, nor will problems connected with the measurement of the collected activity. One of the main instrumental problems, however, is to maximize the amount of dust collected per unit of time on a restricted collection surface, as the overall sensitivity of the measurement will be determined by the surface density of the collected activity. In previous work on electrostatic precipitators for measurement purposes it has often b implicitly assumed that the best operating point of precipitator is at nearly 100% efficiency. It will be sho that the greatest sensitivity and accuracy is obtained at than approximately 30% efficiency.

DESCRIPTION OF THE INSTRUMENTS

In the continuous air monitor the dust is collected o 0·05 mm thick aluminium tape 7 cm wide. The tape sup takes 110 m of the tape. In Fig. 1 a top view of the in ment is shown. The tape moves from the tape supply a contact, sensing the tape tension, through the precipita and then past the scintillation detectors. These can placed at any position along the tape on either side of shielding wall in the middle. The tape is finally wound on the take-up reel. The tape is fed discontinuously at a time. The lowest mean speed is 1 cm/h and the high is 500 cm/h. The longest delay between collection measurement is 85 h and is obtained at the lowest tape sp using a detector position at the lower right end of the shiel wall. The shortest delay is 1·2 min with the detector

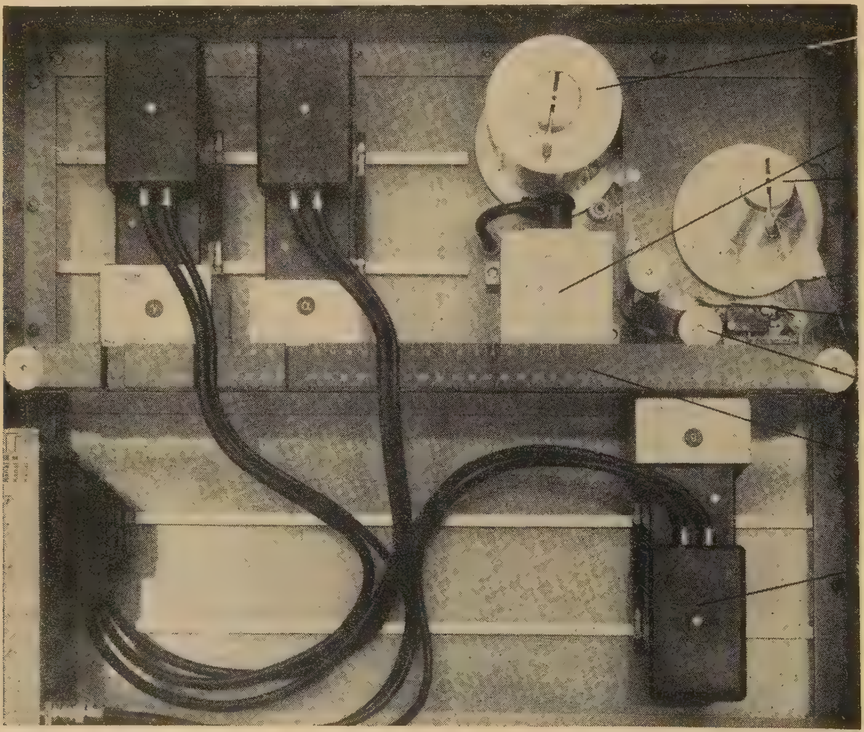


Fig. 1. Top view of the continuous air monitor

the precipitator. The tape transport system consists of a ple servomechanism described below. The air intake to precipitator is located on the right-hand side of the trument and the exhaust from the blower is on the left e. The normal operating flow rate is approximately 3 m^3/min. The blower used is an Electrolux type Z 33 unted in a unit which is easily removed. The speed the blower can be regulated by means of a variable nsformer.

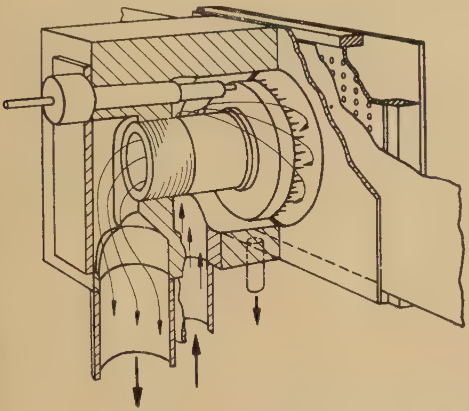


Fig. 2. Cut-away view of the electrostatic precipitator

A cut-away view of the precipitator is shown in Fig. 2. a cylindrical cavity a high voltage electrode is mounted on tubular insulator. The electrode has a number of fine ints from which a corona discharge to the collection face on the tape is obtained. The aerosol passes the charge region. On the back side of the tape there is a tion plate which prevents the tape from being sucked vards the discharge points as the precipitator normally has ower pressure than the surroundings. The suction plate is connected to the input of the blower to give a lower pressure than that at any point in the precipitator cavity. In Fig. 2 the direction of air flow indicated by arrows is from the rim of the electrode towards its centre and through the insulator. The properties of this precipitator and the high voltage supply will be discussed in the next section.

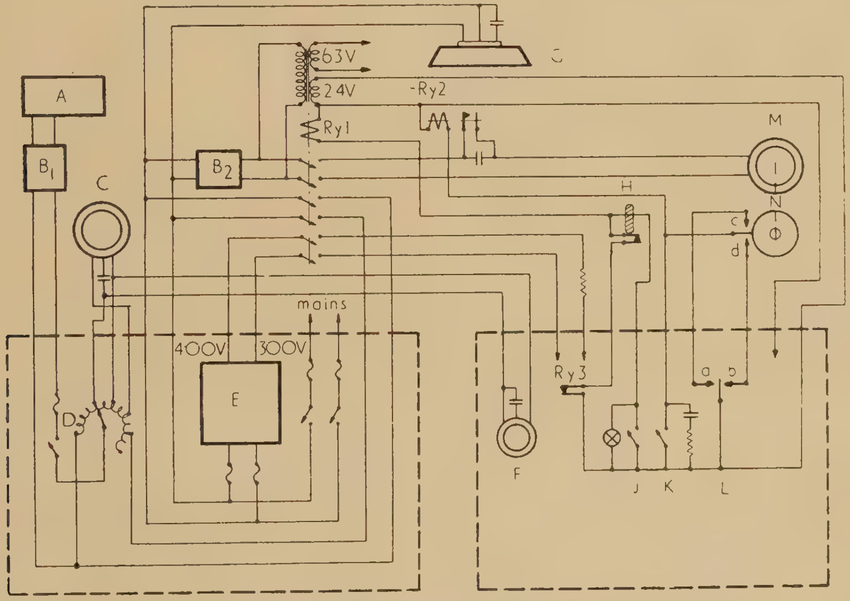


Fig. 3. Block diagram of the continuous air monitor

A, blower; B_1, B_2, filter 1 and 2; *C*, brake motor; *D*, Variac; *E*, power supply; *F*, timing motor; *G*, cooling fan; *H*, tape tension contact; *J*, start switch; *K*, fast forward switch; *L*, pulse generator; *M*, take-up motor; *N*, measuring roller.

A block diagram of the instrument is shown in Fig. 3. As shown in the diagram the main relay (*Ry* 1) must be closed by the push-button marked "start" to start the blower, the high voltage supply for the precipitator and the tape transport mechanism. If the tape supply becomes empty or if the tape tension is too low the tape contact will break this relay. It is also broken if the high voltage supply is overloaded. The detectors, however, are independent of this relay and continue to operate. Not shown are the circuit diagrams of the three detector channels as these are fairly standard. The detectors are α-, β- and γ-sensitive scintillation detectors using zinc sulphide, anthracene and thallium-activated sodium iodide, respectively, as phosphors. There are two identical counting-rate meter channels with five ranges. The lowest range is 100 pulses/min, and the highest is 10 000 pulses/min. Two different integrating time constants may be chosen. To make use of the very low counting rate of the α-sensitive channel the following simple method is adopted. The pulses from the detector are fed to a scale of sixteen, the output of which drives the pen recorder *via* a cathode follower stage. When the last scaling stage triggers, the pen traverses from one position to another. The line density on the paper is thus a measure of the counting rate. The highest line density that is countable at normal paper speed corresponds to a counting rate which can be measured on the lowest range on the counting-rate meters. The different channels may be used interchangeably for any of the detectors. The signal pulses from the photomultipliers are amplified sufficiently (seventy-five times) at the detector units before being fed to the counting units in order to reduce the pick-up of noise.

In the portable dust sampler, a modified vacuum cleaner, the same type of precipitator is used, operated at slightly lower ratings. The air flow rate is approximately 0·6 m^3/min. The dust is precipitated on an aluminium plate, which is subsequently placed in α-, β- or γ-sensitive detectors for measurement of the activity. The high voltage supply for the corona discharge is built into the space normally occupied by the bag in the vacuum cleaner. The blower operates at normal voltage and the air flow is measured only when precision measurements are made or when the instrument is calibrated. A small shunting flow of air is used to cool the high voltage supply. As a safety measure there is a switch which breaks the high voltage supply when the collection plate is removed.

ELECTROSTATIC PRECIPITATOR

It is of prime importance to have a constant efficiency in a precipitator for measurement purposes. If n_0 is the number of dust particles of radius r per unit volume at the input to the precipitator and n at the output, the efficiency of collection is defined as

$$p = (n_0 - n)/n_0$$

A second requirement is to have a high sensitivity, i.e. to maximize the number of particles collected in unit time per unit of area. As in all practical cases, the aerosol to be measured may be considered to be of infinite extent; this implies that the product of efficiency p and air flow rate q should have the highest value.(4) This is contrary to the case of precipitators for air cleaning which, of course, should have the highest possible efficiency.

The well-known expression(5–7) for the exponential dependence of precipitator efficiency on collection surface area S, air flow rate q and particle drift velocity v towards the collection surface will be derived for the geometry used in this case. The circular collection surface has the radius b. The corona discharge points are considered to be evenly distributed over this area, giving a mean particle velocity v independent of the radial distance R from the centre of the collection surface. The particle drift velocity v is dependent on the electrical properties of the corona discharge, and if these are kept constant it becomes a function of the particle size, $v = v(r)$ where r is the particle radius. If n is the number of particles of radius r per unit volume at R, the number of particles collected in the time dt on the surface element $2\pi R\,dR$ is $2\pi R\,dR\,nv\,dt$. Hence, the decrease in the particle concentration in the volume element $2\pi R\,dR\,d$, where d is the distance from the precipitator head to the collection surface, will be

$$dn = -\frac{nvdt}{d} = -\frac{2\pi Rnv}{q}dR$$

Integration of this equation between some lower limit a in case there are no discharge points at the centre within an area of radius a, and the outer radius b gives

$$n = n_0 \exp\left[-\pi(b^2 - a^2)v/q\right]$$

and hence the efficiency is

$$p = \frac{n_0 - n}{n_0} = 1 - \exp\left[-\pi(b^2 - a^2)v/q\right]$$
$$= 1 - \exp(-Sv/q) \quad (1)$$

In this case we may take $a = 0$ as an approximation, though the corona discharge point density is much les the centre where the air exhaust (or intake) is located. collection area S has been chosen to match the sensitive of 2 in. photomultiplier scintillation detectors and is appr mately 16 cm^2 for both types of instruments. In the tinuous air monitor consideration of the time resolutio the instrument has led to the same collection area.

The functions p and pq are shown in Fig. 4, in which a dimensionless variable defined as $1/x = Sv/q$; functio tends towards a saturation value equal to Sv when the flow is increased. The precipitator is normally operate an air flow giving less than approximately 30% efficie ($x > 3$). This mode of operation has some further advanta besides giving a high value of pq. As the air flow is increa the amount of dust collected tends to become indepen of the air flow rate, i.e. the sensitivity of the instrument be less affected by variations in the flow rate. At the no operating point a 15% change in air flow rate will give than 2% change in sensitivity. For the geometry use this precipitator the theory outlined is valid up to linear air velocities comparable to the ion drift velociti the corona discharge. Experiments with collection on evaporated glass plates, permitting observation of the co discharge, showed that at mean linear air velocities in discharge region of approximately 50 m/s the broom-sha discharges from the points get distorted, indicating that ions are blown away. At these very high flow rates collection becomes erratic.

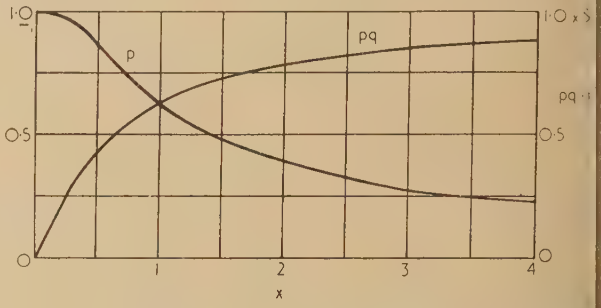
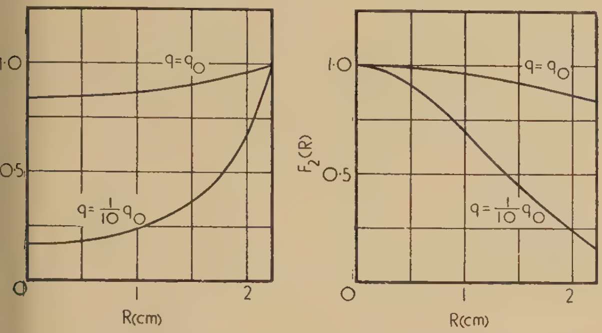


Fig. 4. Collection efficiency (p) and collection efficien times air flow rate (pq) as a function of air flow rate

At the normal operating point ($x > 3$) a nearly unif distribution of dust over the collection surface is obtai This is of special importance when measuring α-activit order to reduce self-absorption in the dust layer. Under same assumptions as used in deriving equation (1) an ideal distribution function $F(R)$ may be obtained by taking derivative of pq, such that $F(R)\,2\pi R\,dR$ is the total num of particles collected per unit of time. Different distribu functions are found for the two directions of air flow.

These functions are shown in Fig. 5 for two different flow rates, for the normal rate q_0 and for $\frac{1}{10}\,q_0$. The number of particles collected is, of course, equal for the directions of air flow. For q_0 the distribution functions approximately the same shape, giving a fairly unif distribution of the dust over the collection surface. For on the other hand, there is a marked difference in the shapes. This change in the shape of the dust distribution different air flow rates or, equally, for different par velocities $v(r)$ is important when attempting to measure total activity of a heterogeneous aerosol. The air direction chosen is with the air outlet at the centre. In continuous air monitor this will give the lowest air pres he centre of the aluminium tape, reducing the risk of tape being sucked into the precipitator. This flow ction also has the advantage that very large particles 0·5 mm) which are easily precipitated will stay in a on with lower linear air velocity, thus reducing the risk they be blown off the collection surface. This has asionally been observed for dust in the form of textile es 1 or 2 mm in length. In order to obtain a uniform ribution of dust in different directions on the collection ace, the air intake tube is tangential to the cylindrical ity. This gives a rotation of the air around the pre-tation head which tends to make the mean air flow ropic.



ig. 5. Distribution of the dust over the collection urface. $F_1(R)$ is obtained when the air outlet is at the entre, and $F_2(R)$ refers to the opposite air flow direction

he initial experiments on electrostatic precipitators for purpose were made with arrangements in which the air am first passed an extended discharge region before pre-tation. This geometry was discarded because at low air rates when charging is sufficient one cannot avoid cipitation of the particles to nearby surfaces in the dis-rge region, and at higher rates the charging becomes fficient for the small collection area wanted. In the cipitator described "electric wind" effects(8) due to the nse corona discharge explain the high particle velocity ined, which is a factor of ten higher than in usual electro-ic precipitators. Measurements on natural aerosol vity ($r \leqslant 1\ \mu$) have shown that values of more than 100 cm/s are easily obtained as compared to 10 cm/s given for the limiting velocity of particles of this size in a Cottrell-type precipitator.(6,9) In the broom-shaped corona discharge the ions will transfer momentum to the air molecules and in turn to the particles in the aerosol, creating a wind towards the collection surface, which brings the particles in close proximity to this surface, where electric and, for very large particles, centrifugal forces (as the stream lines form closed circuits) may act in the actual precipitation process. The particles will take up some charge while passing the space charge region, and as there is a rapid change in the potential immediately in front of the collection surface, the drift velocity will be high across this region of large gradient. If this layer of high electric field strength did not exist, the effect of the "electric wind" would only be to increase the turbulence in the gas.

In this work negative corona has been used exclusively as this gives a larger existence range of the discharge.(6) The existence range is the difference between the sparking voltage and the corona starting voltage. A disadvantage is that it has much higher ozone production rate than the positive corona. The Townsend expression for the corona current-voltage characteristic

$$I = \text{const}\ V(V - V_c) \qquad (2)$$

shows that the corona current I is a parabolic function of the impressed voltage V above the starting voltage V_c. The value of V_c depends on the point-to-plane distance, the point radius and the surface conditions of the point. In this case there are a large number (120) of discharge points working in parallel. Any spread in the discharge properties of the points results in a large spread in corona currents and in a reduction of the effective existence range of the ensemble as compared to a single point discharge. For this reason the points should be carefully mounted on the head. The points consist of ordinary sewing needles which are soldered into holes in the precipitator head. In this operation the needles are pushed towards a plane surface. The whole precipitator head is gold plated to withstand the corrosive atmosphere in the discharge. To avoid a discharge from the first line of points to the precipitator wall the electric field is modified by means of a rim, which projects to within 1 mm from the plane through the points. This precaution was found necessary to confine the precipitation to the collection plate.

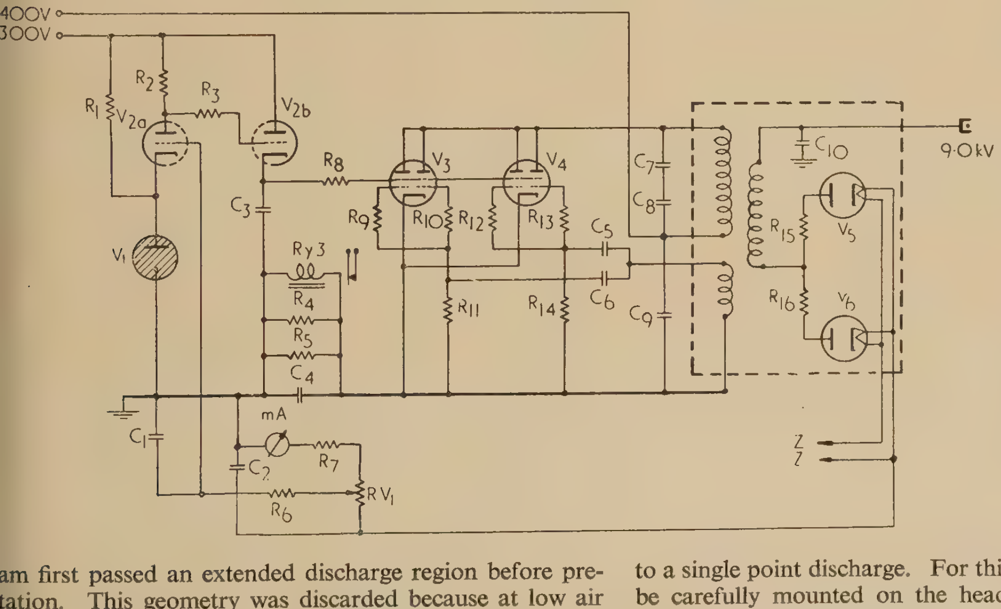


Fig. 6. Schematic diagram of the high voltage supply

R_1 = 50 kΩ
R_2 = 100 kΩ
R_3 = 1 MΩ
R_4 = 125 Ω
R_5 = 200 Ω
R_6 = 0·5 MΩ
R_7 = 20 kΩ, w.w.
R_8–R_{10} = 100 Ω
R_{11} = 25 kΩ
R_{12}, R_{13} = 100 Ω
R_{14} = 25 kΩ
R_{15}, R_{16} = 2·7 kΩ

RV_1 = 10 kΩ, w.w.

C_1 = 0·01 μF
C_2 = 0·03 μF
C_3 = 0·02 μF
C_4 = 2·0 μF
C_5, C_6 = 820 pF
C_7, C_8 = 0·01 μF
C_9 = 1·0 μF
C_{10} = 500 pF, 20 kV

V_1 = 85A2
$V_{2a,b}$ = 12BH7
V_3, V_4 = QQE O3/12
V_5, V_6 = EY51

It has been observed by Mierdel(10) and others that the dust loading of the electrostatic precipitator has a marked influence on the current-voltage characteristic of the discharge, giving an additive term in V_c proportional to the dust concentration. This effect gives a non-linear response of the precipitator, but can be reduced by keeping the input current constant. From the parabolic form of equation (2) it is also evident that to get a well defined working point of the discharge, we should keep the corona current constant and not the voltage. A point-to-plane distance of 5 mm will give an operating voltage of approximately 8·3 kV. In the portable air monitor the current is adjusted to approximately 1·8 mA and in the continuous air monitor it is 3 mA.

For the high voltage supply a radio-frequency resonant transformer was chosen, because of ease of regulation and the small filter capacitance necessary. The small output capacitance is of advantage as a spark is suddenly quenched and the build-up of voltage after the spark is rapid, thus reducing the time of ineffective precipitation. A schematic diagram of the high voltage supply is shown in Fig. 6. The current from the lower side of the secondary winding of the resonant transformer passes through a wire-wound resistor and an adjustable part of the voltage developed is fed to V_{2a}. The difference between this voltage and that developed by the voltage stabilizer V_1 in the cathode is amplified and modulates the screen grids of the oscillator valves. To avoid the deterioration observed when the high voltage transformer is exposed to air it is enclosed in an oil filled can. This unit also contains the filter capacitor and the two rectifier diodes. The can measures $6 \times 6 \times 8{\cdot}5$ cm^3. The d.c. efficiency of this supply is approximately 45%. The operating frequency is around 80 kc/s.

TAPE TRANSPORT MECHANISM

The tape is fed discontinuously by means of a simple pulse operated servomechanism. This system gives a large range of different tape speeds only by electrical switching. There is one switch to select the speeds 1, 2, 3, 4 or 5 cm/hour and another switch which gives a fast forward position, stop and three multiplier positions, ×1, ×10 and ×100. The lowest speed is thus 1 cm/hour and the highest 500 cm/hour. At each pulse the tape moves 1 cm, which is small enough to give a fair averaging of the collected activity along the tape, as the precipitator has a collection area of approximately 4·5 cm diameter.

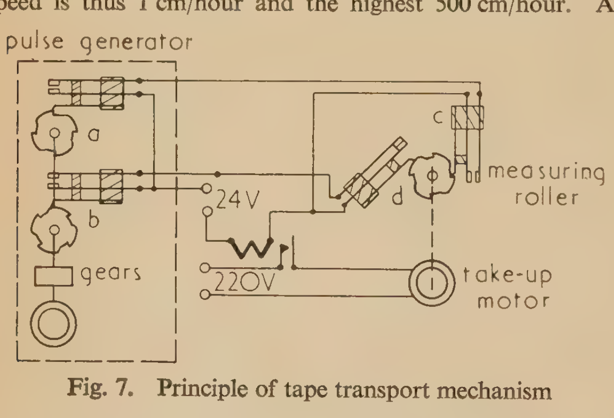


Fig. 7. Principle of tape transport mechanism

The principle of operation of this system can be explained with the aid of Fig. 7. From the tape supply reel, which is coupled to a braking motor the tape moves past a measuring roller, passes the precipitator and detectors and is finally taken up on a reel, driven by a worm-gear reduction mot
The measuring roller has a circumference of exactly 8
and it is coupled to a cam which operates two breaki
contacts *c* and *d*, closing one circuit before breaking
other. The two contacts *a* and *b* in the pulse generator
cam operated in such a way that the contacts are alternat
closed for a few seconds. Eight breaks are made per revo
tion of the measuring roller, which gives 1 cm of tape tra
per pulse. When contact *a* in the pulse generator is clos
the relay will start the take-up motor only if the correspondi
contact *c* at the roller is closed. The motor will work u
the roller has rotated one eighth of a revolution, wh
contact *c* breaks and *d* is closed, making the system ready
start on the next pulse, i.e. on closing of contact *b*. Ea
operation takes approximately one second. The pu
generator has three cam shafts, each with five pairs of ca
The first is driven at 50 rev/h by a synchronous motor,
second at 5 rev/h and the third at 0·5 rev/h. Switchi
different pairs of cams gives the number of pulses
revolution of the shaft and switching different shafts gi
the multipliers ×1, ×10 and ×100. Mounting and adju
ment of the rollers and the reels has to be done with so
precision in order to avoid "climbing" of the tape on
rollers. Once adjusted, the tape transport system descri
is completely reliable in operation.

MEASUREMENTS

The sensitivity of these instruments is determined by
product of collection efficiency *p* and the air flow rate *q* a
the efficiencies and background counting rates of the detecto
In the continuous air monitor the sensitivity is, of cour
inversely proportional to the tape speed. For the scintilla
detectors used in the continuous air monitor the backgrou
counting rates are approximately 8 pulses/h, 80 pulses/m
and 200 pulses/min for the α-, β- and γ-sensitive channe
respectively. Assuming a 50% increase in these counti
rates as the lowest significant value, at the lowest tape spe
of 1 cm/h and for a *pq* value of 0·20 m^3/min, the limits
sensitivity are $1{\cdot}5 \times 10^{-15}$ μc/ml., $1{\cdot}3 \times 10^{-12}$ μc/ml. a
$1{\cdot}0 \times 10^{-11}$ μc/ml. for α-, β- and γ-emitters, respective
These levels should be compared to the maximum permissi
levels of unspecified air-borne activity(11), which
5×10^{-12} μc/ml for α-emitters and 1×10^{-9} μc/ml.
β- or γ-emitters. The high sensitivity of the α-chan
cannot be fully used, even at the maximum delay time
85 h, owing to too slow decay of some products in the natu
aerosol.

The constancy of the sensitivity or the *pq* value of th
precipitators has been determined in repeated paral
measurements with two instruments sampling the sa
aerosol at the same time. The mean deviation in the ra
of the amounts of activity collected was 0·7%. This fig
includes variations in sensitivity of the detectors, but
main part still comes from the statistical spread in the num
of pulses counted. The measurements were made on
natural aerosol and extended over two months. No adju
ment of the air flow rates was made.

The collection efficiency is determined by two measu
ments(3) in which two precipitators with unknown efficienc
p_1 and p_2 are working in series. The ratio of the amounts
activity in the first measurement is then $p_1/(1 - p_1)p_2$, if
air intake is at the precipitator with efficiency p_1. In
second measurement, when the two precipitators have chang
their places, this ratio will be $p_2/(1 - p_2)p_1$. From th
equations p_1 and p_2 are easily determined. The efficiency

ermined by this method, or by parallel measurements if p is known, for a range of air flow rates. The pq value of precipitator is then obtained by measuring the normal erating flow rate. In the normal operating range the eement between the measured functions pq and p and the oretical curves shown in Fig. 6 is within 1·5%.(9) At y low flow rates, however, there is a marked departure, p ng smaller than the theoretical value. There are several ssible reasons for this behaviour, which is being investigated the present time.

The calibrating procedure described gives consistent ults (i.e. p is constant), if the aerosols consist of small ticles. This indicates that the particle velocity $v(r)$ is nstant for a large range of particle sizes. Let $\rho(r, t)$ be the tribution function of the measured activity on different ticle sizes, such that $\int_0^\infty \rho(r, t)\, dr$ is the total activity per it volume of air. Function $\rho(r, t)$ is, of course, also a iction of time, as both the total content and the shape of distribution may vary. The activity collected in time T the precipitator is then

$$A = q\int_0^T \int_0^\infty \rho(r, t)\left\{1 - \exp\left[-Sv(r)/q\right]\right\} dr dt$$

ly in cases where $v(r)$ is constant or the distribution does t change its shape will the efficiency measured be constant.

APPLICATION OF THE ELECTROSTATIC PRECIPITATOR TO OTHER SAMPLING SYSTEMS

Often it is important to detect a sudden increase of long-ed aerosol activity inside a laboratory or a building with a nimum of delay in a background of high and varying tural aerosol activity. In this case a balanced system(12) ould be used in which there are two channels. One channel easures the incoming ventilating air, and the other the oratory air. When the two channels are adjusted for equal nsitivity the indicated difference will be a measure of the contamination. The present limit of sensitivity of this tem(13) is set by the fluctuations in the ratio of the air flow es of the two channels. Two electrostatic precipitators, erated in the saturation region as described, would give a ostantial improvement in the sensitivity of a balanced tem because of the small variation of the precipitation e with the air flow rate.

As stated in the introduction a time delay system of the pe described is primarily suited for the measurement of a all increase in the general background level due to long-ed activity. It does not give the right contribution to the liation dose from activity of short half life. The informa-n wanted in a health physics measurement is an indication the effects of radiation on man. One step in this direction uld be a system which has a sensitivity directly propor-nal to the half-life of the activity collected. It may be of erest to mention briefly the principles of such a decay-time ective system. The essential features of the proposed tem are shown in Fig. 8. The tape is moving on the tside of a rotating drum and passes through a slit in the ll to the supply and take-up reels. The precipitator, ich is facing the tape on the drum, may have a large ension along the periphery to offer a large collection face and thus a high sensitivity. The detectors are placed the sector not occupied by the precipitator. The drum a diameter of about 60 cm. The time T a point on the tape takes to move from the slit around the whole periphery may be one or several days. The period of rotation of the drum should be short in comparison to the integrating time constants in the output of the counting rate meters.

The input aerosol $\rho(r, t)$ to the precipitator is a sum of activities of different half-lives. Let the collection rate of activity of decay constant λ be $a(t)$,

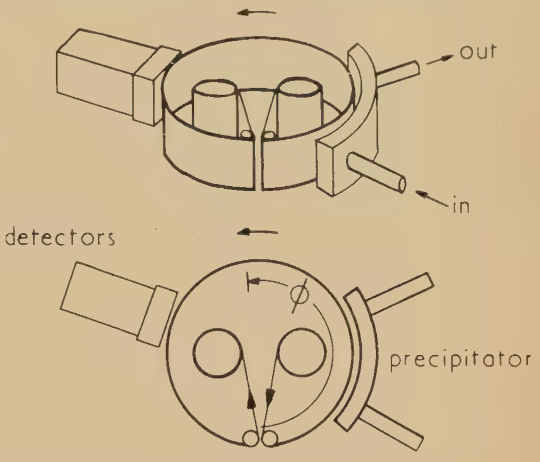


Fig. 8. Proposed rotating drum sampling system

$$a(t) = q\int_0^\infty \rho(r, t)\left\{1 - \exp\left[Sv(r)/q\right]\right\} dr$$

The surface density of this activity at an angle ϕ is denoted by $\Omega(\phi, t)$. The angle ϕ is measured from the slit in the same direction as the tape moves on the drum. This point on the tape has been exposed for a time $\phi T/2\pi$ where T is the total exposure time.

Then

$$\Omega(\phi, t) = \alpha\int_0^{\phi T/2\pi} a(t - x)\exp(-\lambda x) dx$$

where α is a constant (including the angle subtended by the precipitator).

The counting rate $R(t)$ of the detectors is obtained by taking the mean value of $\Omega(\phi, t)$ over the range of ϕ. Thus

$$R(t) = \frac{\alpha\beta}{2\pi}\int_0^{2\pi}\int_0^{\phi T/2\pi} a(t - x)\exp(-\lambda x) dx d\phi$$

where β is a constant.

To show the main idea we take for simplicity a as a constant. Then

$$R(t) = \frac{\alpha\beta a}{\lambda}\left\{1 - \frac{1}{\lambda T}\left[1 - \exp(-\lambda T)\right]\right\}$$

For $\lambda \to 0$, i.e. for activity of very long half-life as compared to T, $R(t) \to \alpha\beta\tfrac{1}{2}aT$, and for $\lambda \to \infty$, $R(t) \to \alpha\beta(a/\lambda)$. The counting rate is thus a mean value in the sense of these equations of the activity collected in the time T, and for short-lived activity it is proportional to the half-life.

This sampling method may be applied to a balanced system. It is also possible to operate this system with a fixed delay. In this case the drum is made stationary, and different delay times are obtained by phasing the slit with respect to the precipitator and the detector. The time resolution, however, will be inferior in this case, if the angle subtended by the precipitator is greater than that of the detectors. The frictional force on the tape would present no problem, though the final tension F is an exponential function of the coefficient of friction, $F = F_0 \exp(\mu 2\pi)$. It is believed that this system would be an improvement over the previous system, as it should permit the extraction of more information on radioactive aerosols.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the invaluable assistance of Messrs. B. Johnsson and S. Eriksson in the initial experiments on electrostatic precipitators, and in the later developments of the instruments Messrs. P. O. Dubois, A. Franzon and E. Holmstrom. He is indebted to Mr. L. Carlbom for his interest in this work and to Dr. D. Taylor, Atomic Energy Research Establishment, Harwell, for an interesting discussion on the measurement problem.

REFERENCES

(1) Kuper, J. B. H., Foster, E. H., and Bernstein, W. *Nucleonics*, **6**, (4) p. 44 (1950).
(2) Wilkening, M. H. *Nucleonics*, **10**, (6) p. 36 (1952).
(3) Carmichael, H., and Tunnicliffe, P. R. *CRTec-* (NRC–1762) (Canada: National Research Coun 1947).
(4) Bergstedt, B. A. *AEF Internal Report* AB Atomene Stockholm (June, 1952).
(5) Deutsch, W. *Ann. Phys.* [*Leipzig*], **68**, p. 335 (1922)
(6) v. Engel, A., and Steenbeck, M. *Elektrische Gasen dungen*, Vol. 2, p. 230 (Berlin: Springer, 1934).
(7) White, H. J. *Elect. Engng*, **71**, p. 67 (1952).
(8) Deutsch, W. *Ann. Phys.* [*Leipzig*], **76**, p. 729 (1925)
(9) Bergstedt, B. A. *International Conference on Peaceful Uses of Atomic Energy*, *Paper* 788, Sec. 23 3, (Geneva, 1955).
(10) Mierdel, G. *Wiss. Veröff. Siemens-Konzern*, **13**, p. (2) (1934).
(11) *Handbook* 52 (Washington: National Bureau Standards, 1953).
(12) Rainey, C. T. UCRL-1391 (U.S. Atomic Ene Commission, 1951).
(13) Taylor, D. *Nucleonics*, **12** (10), p. 12 (1954).

An improved helium liquefier and cryostat

By D. F. Brewer, M.A., D.Phil., and D. O. Edwards, B.A., Clarendon Laboratory, University of Oxford

[*Paper received* 5 *October*, 1955]

A Linde helium liquefier-cryostat suitable for visual observations is described. It is similar to the Daunt and Mendelssohn type,(1) but has greatly improved characteristics. Modifications have been made in the method of pre-cooling the circulating gas to 90° K and in the heat interchangers. A separate 14° K stage has also been incorporated. About 750 cm³ of liquid are produced at the rate of one litre per hour.

For some years, many experiments on the properties of liquid helium have been carried out in this laboratory using small-scale combined liquefier-cryostats of the type described by Daunt and Mendelssohn.(1) From time to time, minor modifications have been incorporated into the original liquefiers, but no basic alteration in the design and performance has been made. These liquefiers produce about 250 cm³ of liquid helium at a rate of 4–5 cm³/min. The heat influx to the cryostat is very small, corresponding to an evaporation rate of 1 to 2 cm³ of liquid per hour. In such a combined liquefier the liquid can be kept extremely free from contamination. This condition is essential when investigating the transport properties of the helium II film, which is strongly dependent on the presence of impurities.(2)

In view of the occasional necessity for using larger quantities of liquid helium while retaining the advantages of the old liquefiers, the apparatus has now been re-designed to produce about 750 cm³ of liquid at a greatly increased rate of liquefaction.

THE APPARATUS

The Joule–Thomson method of cooling has been retained in the present apparatus, the principal modifications being the re-designing of the heat interchangers, and the incorporation of a metal reservoir inside the vacuum case to contain liquid hydrogen boiling under reduced vapour pressure.(3) This introduces a slight complication, but has two advantages. First, it avoids the necessity of pumping the hydrogen in the glass Dewar vessel and reducing temperature of the outside of the apparatus to about 15° thereby decreasing appreciably the consumption of liq hydrogen. Secondly, the reservoir can be re-filled wh necessary during liquefaction in less than a minute, and temperature rapidly reduced again. With the old liquefie this operation takes 5 to 10 minutes, during which liquefact virtually ceases.

The consumption of liquid oxygen has been considera reduced by dispensing with the pre-cooling well which w included in the top of the old liquefiers, and which was v wasteful of liquid oxygen. This also has the advantage t the control knob of the expansion valve remains at ro temperature, and never becomes frozen. The initial p cooling to the temperature of liquid oxygen now takes pl outside the apparatus (see below). The design and circ of the liquefier are shown diagrammatically in Fig. 1.

Helium gas at about 23 atm is purified and cooled to 90° by passing through the two activated charcoal cleaners and A_2, and the pre-cooling coil C_1, all immersed in liq oxygen. From C_1 it is led into the top of the liquefier throu the copper tube T, which is insulated by a vacuum jacket.

The high-pressure helium then passes through the f heat interchanger E_1, where its temperature is reduced approximately 37° K, and through the coil C_2. The wh apparatus including E_1, is surrounded by a Dewar ves not shown, containing liquid hydrogen up to a level j below E_1. From C_2 a cupro-nickel tube leads the gh the top of the vacuum case V to the second heat hanger E_2 (approximately 86% efficient) and thence to ird coil C_3 inside the vessel P. Liquid hydrogen may mitted to P from the main hydrogen bath by means of a e valve, and the vapour pressure reduced to a value sponding to about 14·5° K. After passing through the heat interchanger E_3, which has an efficiency of approxi- y 95%, the helium is expanded through the adjustable N_1 to an overpressure of 0·3 atm. Part of the gas

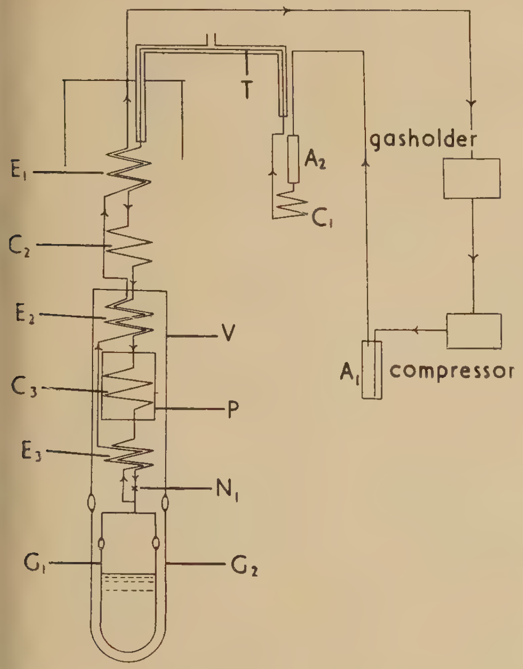


Fig. 1. Block diagram of liquefier and gas circuit

fies and drops into the glass cryostat G_1, the remainder ning through the three heat interchangers back to the holder. The glass cryostat G_1 and the glass vacuum t G_2 are attached to the metal parts of the apparatus neans of Kovar seals, and the liquid may be viewed ugh narrow slits in the hydrogen Dewar vessel and in the d oxygen Dewar vessel which surrounds the lower part

PERFORMANCE

e procedure in carrying out a liquefaction is given below e form of a time-table:

(min.)

0 Apparatus at room temperature with vacuum case and hydrogen vessel P pumped out. Dewar vessel around apparatus filled with liquid oxygen, and exchange gas admitted to vacuum space.

0 Apparatus at 90° K. Exchange gas pumped out. Liquid oxygen in the Dewar vessel replaced by liquid hydrogen and exchange gas then admitted.

5 Apparatus at 20° K. Exchange gas pumped away (approximately 5 min), liquid hydrogen admitted to P and its vapour pressure reduced to about 6 cm of mercury.

0 Helium circulation begun.

8 Liquid helium appears in G_1.

e starting time, given above as eight minutes, depends he size of cryostat to be filled, since the determining factor is not the heat capacity of the liquefier system, but the volume which has to be filled with helium gas at 4·2° K. The time of eight minutes refers to a cryostat of 750 cm³ capacity.

Once started, the liquefaction proceeds at a rate of over one litre per hour with an over-pressure of one third of an atmosphere in G_1. This rate could probably be increased by using a larger compressor than the present one which has a capacity of 6 m³ per hour.

To cool the apparatus, four litres of liquid oxygen and about two litres of liquid hydrogen are required. The production of one litre of liquid helium requires five litres of liquid oxygen and less than two litres of liquid hydrogen. It is necessary to re-fill the hydrogen vessel P once during the liquefaction of 750 cm³ of helium, but this can be done without stopping the circulation.

After liquefaction, the normal evaporation rate from the cryostat is about 2 cm³ of liquid per hour.

DETAILS OF THE CONSTRUCTION

A scale drawing of the apparatus is given in Fig. 2, and the dimensions of the heat exchangers in the table. The exchangers E_2 and E_3 each consist of two coaxial tubes wound into a spiral, while E_1 consists of three high-pressure

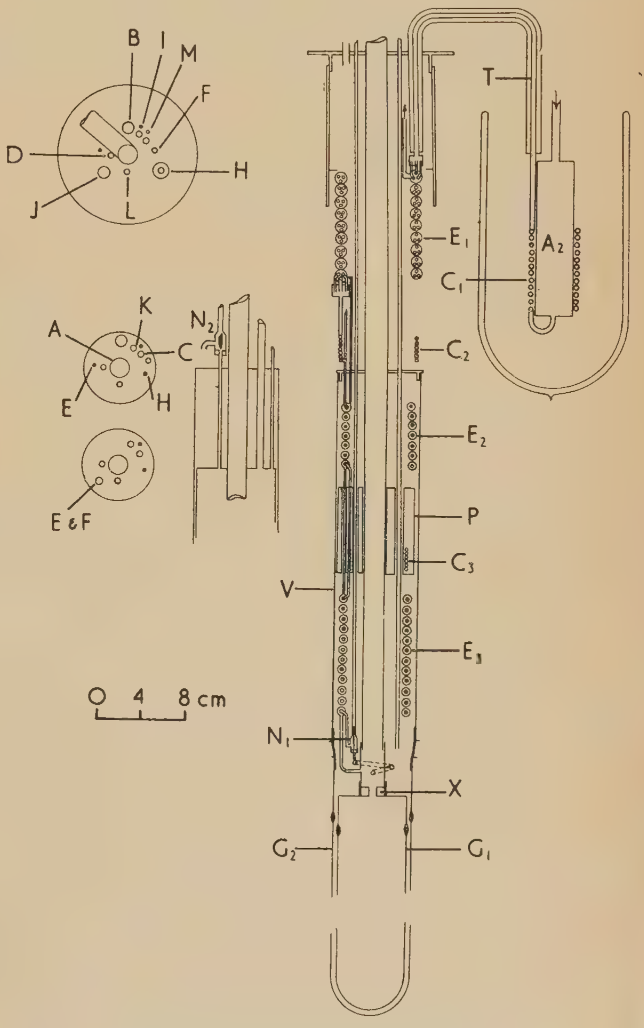


Fig. 2. Scale drawing of liquefier

tubes enclosed in a single low-pressure tube. The pre-cooling coils are all of copper (C_1 = 190 cm long, 2 mm inner diameter, and 3 mm outer diameter; C_2 = 175 cm long, 1·5 mm inner diameter, 2·5 mm outer diameter; C_3 = 65 cm long, 1 mm inner diameter, 2 mm outer diameter). Connexions between the low-pressure parts of the interchangers, and to the return-line to the gas-holder, are made of wide-bore cupro-nickel tubing to avoid undesirable pressure-drops, and the tube connecting E_3 to E_2 is insulated from the hydrogen vessel by a Nylon thread wound around it. The sizes of other tubes are as follows:

- *A*, cryostat pump, 15 mm German silver.
- *B*, vacuum jacket tube, 10 mm German silver.
- *C*, additional vacuum tube, 6 mm German silver.
- *D*, expansion valve, 4 mm German silver.
- *E*, gas thermometer, $\frac{1}{2}$ mm German silver.
- *F*, low pressure helium outlet, $\frac{5}{32}$ in. cupro-nickel.
- *H*, high pressure helium inlet, jacket $\frac{1}{2}$ in. cupro-nickel containing $\frac{1}{8}$ in. copper tube.
- *I*, manometer tube to measure pressure after C_3, 1 mm inner diameter cupro-nickel.
- *J*, hole for liquid hydrogen siphon, 10 mm German silver.
- *K*, hydrogen pump, 6 mm German silver.
- *L*, liquid hydrogen valve, 4 mm German silver.
- *M*, manometer tube for *P*, 1 mm inner diameter cupro-nickel.

Details of heat interchangers

	Length (cm)	*High-pressure copper tubes*	*Low-pressure cupro-nickel tubes*	*Internal diameter of coil* (cm)
E_1	230	3 tubes: 1 mm inner diameter 2 mm outer diameter	$\frac{1}{4}$ in. outer diameter 24 gauge	6·2
E_2	105	1 tube: 1 mm inner diameter 2 mm outer diameter	$\frac{3}{16}$ in. outer diameter 22 gauge	5·4
E_3	210	1 tube: 1 mm inner diameter 2 mm outer diameter	$\frac{3}{16}$ outer diameter 22 gauge	5·4

A gas thermometer of about 1 cm^3 in volume, not shown, is soldered to the expansion valve assembly N_1 in order to observe its temperature during pre-cooling and liquefaction. Both needle valves, N_1 and N_2, consist of a stainless steel cone, total angle 5°, fitting into a 1 mm hole in a brass seat. They are operated by $\frac{1}{8}$ in. stainless steel tubes passing through packings at the top of the liquefier. The 5 cm length of 1 mm German silver tube which leads from the expansion valve to the cryostat, reduces the heat input down the copper tubes of the heat interchangers when the liquefaction is finished. A constriction *X*, length 7 mm and diameter
reduces the heat influx to the cryostat caused by the heli
film.

The hydrogen vessel *P* is made of copper, with four c
sleeves hard-soldered into it through which the tubes
D, *E* and *F* pass down to the lower part of the liqu
This method lessens the danger of leaks from *P* int
vacuum space. Vessel *P* may be filled by sucking in
from the main hydrogen bath through the adjustable r
valve N_2. The vapour pressure in *P* is measured by mea
the tube *M* connected to a dial gauge, and the hydrog
pumped through the 6 mm German silver tube *K*. It i
necessary to use a large pump for this purpose.

Electrical leads may be led into the cryostat either th
the central tube of the liquefier, or through the 6 mm Ge
silver tube *C*. When using the latter method, it is advi
to provide a "thermal anchor" for the leads at 20° K.
tube *C* can also be used in experiments where an addit
inner vacuum space is required.

ACKNOWLEDGEMENTS

We wish to thank Dr. K. Mendelssohn for valuable ac
and Mr. F. Lenthal for construction of the liquefier.
are indebted to the Nuffield Foundation for a Res
Fellowship (D.F.B.) and to Brasenose College for a S
Hulme Scholarship (D.O.E.).

REFERENCES

(1) Daunt, J. G., and Mendelssohn, K. *J. Sci. Instrum*
p. 318 (1948).
(2) Bowers, R., and Mendelssohn, K. *Proc. Phys.*
[*London*] *A*, **63**, p. 1318 (1950).
(3) Ambler, E. *Proceedings of the Eighth Internat*
Congress of Refrigeration, London, p. 98 (1951).

A magnetic analyser for high energy particles

A. Lovati and H. Tyrén, The Gustaf Werner Institute for Nuclear Chemistry, University of Uppsala, Sweden

[*Paper received* 24 *November*, 1955]

A magnetic analyser for accurate measurement of momentum of nuclear reaction products, employing two-directional focusing with a sector-shaped uniform magnetic field, is described. The instrument is useful for analysing particles with magnetic rigidity up to $2\cdot 10^6$ G cm (corresponding to 180 MeV protons and α-particles, 90 MeV deuterons, etc.).

study of nuclear reactions and, in particular, in the sis of one particle production (elastic and inelastic ns, picked-up deuterons, etc.) by high energy particles, esolution and large transmission are desired.

present paper describes a magnetic analyser, recently at this Institute, which uses a sector-shaped uniform etic field for two-directional focusing. A short summary theory of focusing, following the treatment of Cross,$^{(1)}$ orted and the problem of the choice of the parameters lined. Resolution tests and calibration are described.

TWO-DIRECTIONAL FOCUSING

problem of two-directional focusing with a sector-d uniform magnetic field, with source and image out-he field, was studied first by Cotte.$^{(2)}$ Recently the em has been re-examined by Camac$^{(3)}$ and in a more al way by Garren and Smith$^{(4)}$ and by Cross.$^{(1)}$ The s obtained by these authors form part—as a particular -of a study about sector-shaped non-uniform magnetic by Sternheimer.$^{(5)}$

It leaves the magnetic field at K and runs along the line KB. Let ϵ_1 and ϵ_2 be the angles that the incident and emerging beam make with the wedge normals of the magnet (the angles are taken as positive if they are on the wedge vertex side) and Φ the angle between incident and emerging beam. $AHKB$ is called the "central path."

From geometrical considerations it appears that:

$$\Phi = \Omega + \epsilon_1 + \epsilon_2 \tag{1}$$

Fig. 1 shows also the path $A'H'K'B'$ of a beam of particles of momentum $p + \Delta p$ ($\Delta p \ll p$), the initial position and direction of which differ by small quantities, y and α, from the central path. After it has left the region of the magnetic field, its position with respect to the central path is determined by the co-ordinates X and Y (the notation X_h will be used in the discussion of the equations in the horizontal plane and X_v in those in the vertical plane). According to Cartan$^{(6)}$ the displacement Y, to a first order approximation in y, α and $\Delta p/p$, is:

$$Y = h_y y + h_\alpha \alpha + h_{\Delta p/p}(\Delta p/p) \tag{2}$$

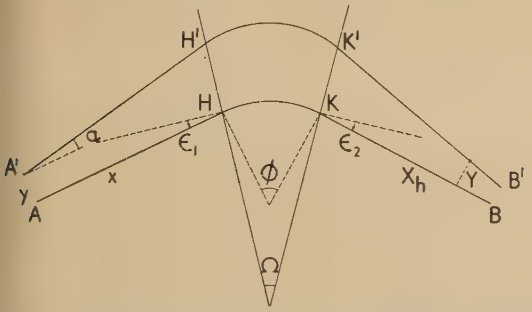
where
$$h_y = \frac{\cos(\phi - \epsilon_1)\cos\epsilon_2 - X_h \sin\Omega}{\cos\epsilon_1 \cos\epsilon_2}$$

$$h_\alpha = \frac{\cos^2\epsilon_1 \cos^2\epsilon_2 - [x\sin\Omega - \cos(\phi - \epsilon_2)\cos\epsilon_1][X_h \sin\Omega - \cos(\phi - \epsilon_1)\cos\epsilon_2]}{\cos\epsilon_1 \cos\epsilon_2 \sin\Omega}$$

$$h_{\Delta p/p} = (1 - \cos\phi)(1 + X_h\, tg\, \epsilon_2) + X_h \sin\Phi$$

rizontal focusing. The horizontal focusing arises by of the differences in length of different particle tra-ies in the magnetic field.

1 shows the median horizontal cross-section of the n. A constant magnetic field B, normal to the plane of



. 1. Particle trajectories in a sector-shaped magnetic field in the horizontal median plane

aper, acts on the particles. Let Ω be the wedge angle e magnet. A pencil of particles of momentum p and s of curvature r in a constant magnetic field B, starting the source A goes a distance x to H and enters the etic field (all the lengths are measured in units of r).

Horizontal focusing will take place when the coefficient of α in equation (2) vanishes,$^{(7)}$ that is for:

$$h_\alpha = h_\alpha(x, X_h, \Omega, \Phi, \epsilon_1, \epsilon_2) = 0 \tag{3}$$

However a second-order effect produces a defocusing, so that the particles from a point source are spread in the small region:

$$Y^* = h_{\alpha\alpha}\alpha^2 \tag{4}$$

where

$$h_{\alpha\alpha} = \frac{1}{2}\left\{\left[\left(\frac{\cos\epsilon_1\cos\epsilon_2}{X_h\sin\Omega - \cos\epsilon_2\cos(\phi - \epsilon_1)}\right)^2 - \cos\phi\right](1 + X_h\, tg\, \epsilon_2) + X_h\sin\Phi\right\}$$

For a source of width y the magnification in the horizontal plane is given by $Y/y = h_y$. A momentum spread Δp of the beam at the source will produce a lateral spread:

$$Y^{**} = h_{\Delta p/p}(\Delta p/p) \tag{5}$$

The minimum value $\Delta p/p$ that the instrument is able to resolve is given by:

$$(\Delta p/p)_{min} = (h_y y + h_{\alpha\alpha}\alpha^2)/h_{\Delta p/p} \tag{6}$$

Vertical focusing. The condition of focusing in the horizontal plane is satisfied by a large number of values of the parameters, which solve the equations (1) and (3) simultaneously.

It is particularly interesting to consider first the case in which $\epsilon_1 = \epsilon_2 = 0$, the beam entering and leaving at right angles to the edges of the magnet. In this case the fringing field does not exert any force on the particles of the central path. The beam is not focused in the vertical plane and at the distance X_v from the exit face of the magnet the displacement Z for a point source is:

$$Z' = g\{1 + [X_v/(x + d)]\} \tag{7}$$

where $2g$ is the gap width and d the length of the path of the beam in the magnetic field. If $dI_z = kd\theta$ is the elementary flux of particles from an isotropic source in the vertical plane, the maximum value of I_z that can be transmitted through the instrument is:

$$I'_z \simeq k[2g/(x + d)] \tag{8}$$

If ϵ_1 and ϵ_2 are not equal to zero, it is possible to achieve vertical focusing. This is due to the field shape at the entrance and exit faces of the magnet, which, if ϵ_1 and ϵ_2 are positive, restores the particles to the median plane. To avoid losing particles at the entrance face by vertical defocusing, ϵ_1 will be chosen positive. The displacement Z from the central path for a beam, the initial position and direction of which differ by small quantities z and β from those of the central path (see Fig. 2), will be, according to Cotte(2), to a first order approximation in z and β:

$$Z = h_z z + h_\beta \beta \tag{9}$$

where

$$h_z = 1 - \Phi\, tg\, \epsilon_1 - X_v[tg\, \epsilon_1 + (1 - \phi\, tg\, \epsilon_1)\, tg\, \epsilon_2]$$

$$h_\beta = \Phi - x(1 - \phi\, tg\, \epsilon_1) - xX_v[tg\, \epsilon_1 + (1 - \phi\, tg\, \epsilon_1) tg\, \epsilon_2] + X_v(1 - \phi\, tg\, \epsilon_2)$$

Vertical focusing will take place when the coefficient of β in equation (9) vanishes, that is for:

$$h_\beta = h_\beta(x, X_v, \Phi, \epsilon_1, \epsilon_2) = 0 \tag{10}$$

When this condition for vertical focusing is satisfied for a source of height z, the magnification in the vertical plane is $Z/z = h_z$. The displacement Z is, in general, not less than the corresponding value for a system without vertical focusing, due to the fact that ϵ_2 may be negative and consequently the fringing field at the exit face produces a defocusing effect.

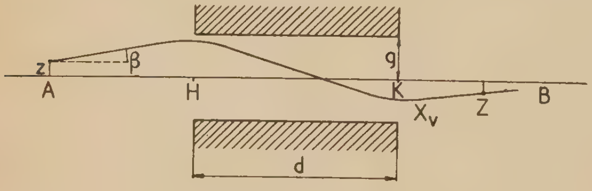


Fig. 2. Particle trajectories in the vertical plane

The value of the flux transmitted in the vertical plane is:

$$I''_z \simeq k\, 2g/x \tag{11}$$

This is always greater than the flux I'_z transmitted through a system without vertical focusing. However, for a non-point source the gain in transmission is generally less than This depends on the fact that for a system with only hori focusing the "useful" height of the source can reac value $[(2x/d) + 1]g$, whereas for a system with d focusing the useful height cannot exceed $(xtg_1 - 1)g$ latter value arises from the analysis of the equations paths of the particles, taking into account the effect fringing field).

Two-directional focusing. With the choice of values parameters that satisfy the equations (1), (3) and (10 the supplementary condition $X_h = X_v$ (which assures the values of X of the equations (3) and (10) are the one gets two-directional focusing.

A complete discussion of the system of four equati the seven variables x, X_h, X_v, ϵ_1, ϵ_2, Ω, Φ is very dif This problem will be discussed briefly in connexion wi choice of the parameters of the magnetic analyser.

CHOICE OF THE PARAMETERS

In choosing dimensions and parameters for a pra analyser, the primary considerations are: gap and mag field radius to be useful to focus particles of desired e solid angle of acceptance and resolution.

In this case protons with a maximum value of around 180 MeV must be analysed, with a maximum a able momentum uncertainty of a few per cent. The mag rigidity corresponding to 180 MeV protons is 2 × 10^6 G cm. Since with a gap of 1·5–2 cm it is p to obtain fields of 20 000 G without very high power minimum radius appears to be of the order of 100 cm solid angle of acceptance is proportional to $(xr)^{-2}$. Ag the choice of too low a value of x there are two argu the angular resolution of the instrument in the horiz plane and the fact that for a low value of x, the angl and ϵ_2 are, according to the conditions of focusing,

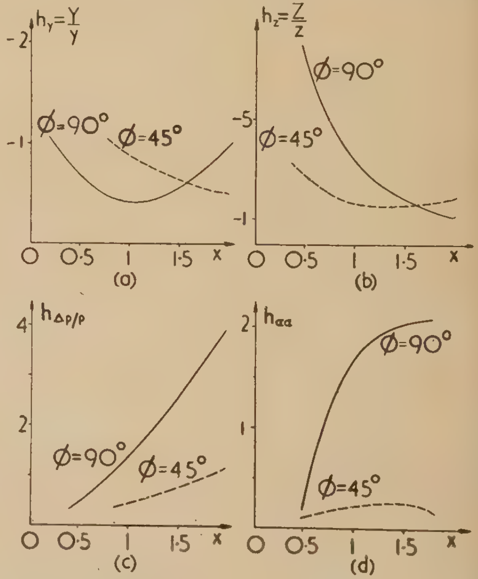


Fig. 3. Variation of h_y, h_z, $h_{\Delta p/p}$ and $h_{\alpha\alpha}$ *versus* $x =$

large to be employed. On the other side, practical consid tions in the use of the instrument do not permit in this xr and Xr to be larger than about 200 cm. It appears convenient to minimize the distance between source image, that is, to set $x = X$.

the choice of the parameters in this particular case the rs have, as a consequence, examined the conditions of ng for $x = X$ between $\frac{1}{2}$ and 2. The graphs of Fig. 3 the variation of h_y, h_z, $h_{\Delta p/p}$ and $h_{\alpha\alpha}$ for $\Phi = 90°$ and s functions of $x = X$. From the graphs it is possible culate the minimum value of $\Delta p/p$ that the instrument esolve: in this case the best values of the parameters r to be $\Phi = 90°$ and x between 1 and 1·5.

DESCRIPTION OF THE APPARATUS

horizontal cross-section of the analyser is shown ig. 4 and the characteristic values are given in the d.

e poles of the magnet have been realized with a width cm and gap height varying between 4·2 and 1·54 cm, with a width of 7·5 cm and gap height 1·65 cm. In to see the effect of this width on the transmission of strument in the horizontal plane, graphical analysis of aths of the particles has been developed. From this it has been possible to find the aperture defining slit e entrance, in order to get 100% transmission in the ontal plane. For 10 cm pole width and a source of = 1 cm this is achieved with a slit of 1·5, 1·2 and 1 cm $\Delta p/p = 1$, 3 and 5% respectively. Transmission of the r of 50% is estimated to be obtained with a slit of 4 cm h for $\Delta p/p = 2{\cdot}5\%$.

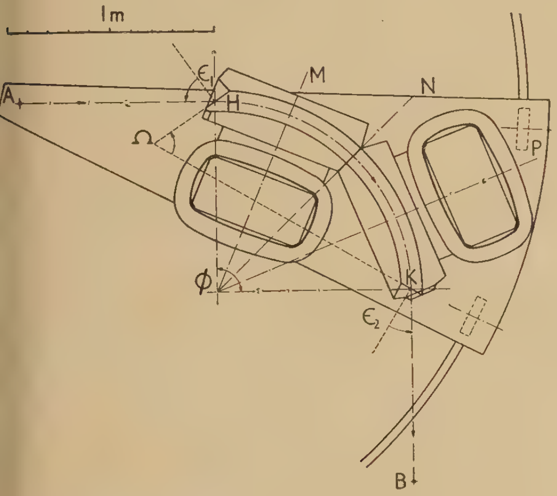


Fig. 4. Section drawing of the analyser

$r = 94$ cm
$x = X = 1$
$h_y = -0{\cdot}41$
$h_z = -3{\cdot}50$
$h_{\Delta p/p} = 1{\cdot}40$
$h_{\alpha\alpha} = 1{\cdot}70$
$z_{\text{max source}} = 0{\cdot}455$ g
$\varepsilon_1 = 55°5'$
$\varepsilon_2 = 30°7'$
$\Omega = 65°2'$
$\Phi = 90°$

he analyser is mounted on a carriage which is pivoted s to rotate around a vertical axis passing through the t source A. The arrangement is such that the angle een the proton beam and the scattered particles in A be varied between 0° and 145°. The magnetic field is luced by two water-cooled coils. The power is delivered a 20 kW motor generator; the current is electronically ilized at 0·1% and its maximum value for continuous ning is 80 A. The magnetic field in the gap has been sured with the coil-fluxometer method, after the coil had been calibrated with the proton resonance system. The field strength, produced by 80 A, is sufficient to deflect 185 MeV protons with a gap of $1{\cdot}65 \times 7{\cdot}5$ cm^2 (deflexions of 150, 100 and 60 MeV can be obtained with gap heights of 1·54, 2·54 and 4·2 cm respectively for 10 cm pole width). The variation of the field along the path $\widehat{HK}$ has been found to be lower than 1%.

TESTS AND RESULTS

The magnetic analyser has been tested in the low energy range, using a source of ThB (half life 10·6 hours), which produces with its decay products three main lines of α-particles: $E_1 = 6{\cdot}086$ MeV (10%), $E_2 = 6{\cdot}047$ MeV (24%) and $E_3 = 8{\cdot}776$ MeV (66%). The height of the gap was 2·54 cm and the path of the rays was in a vacuum tank.

The measurements have been made with Ilford C2 plates which have been put successively along the path of the particles at the entrance and exit faces of the magnet and at the focus of the system.

Using a field strength corresponding to the energy E_3, different experiments have been carried out with sources of different sizes and in different positions with respect to the point A. An analysis of the coefficient of transmissions has been done, counting the transmission for a very small source (about 0·05 cm in diameter) placed successively in different positions with respect to the point source. The results that have been obtained with a slit of $4 \times 1{\cdot}8$ cm^2 are shown in the graph of Fig. 5.

The two lines E_1 and E_2, which present a momentum spread $\Delta p/p = 0{\cdot}33\%$, have been used for testing the predictions for non-monoenergetic source. The distance between the two peaks is in good agreement with the expected value.

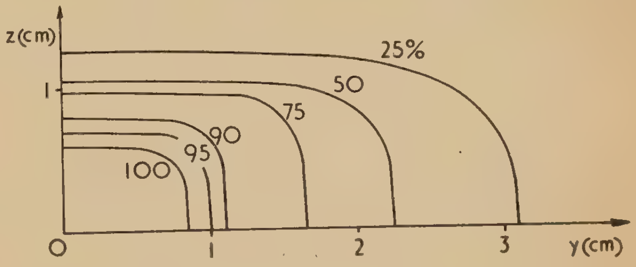


Fig. 5. Transmission coefficient for a diffuse source (the value in the centre has been put arbitrarily at 100%)

The same proofs have been carried out in the high energy range (140 MeV protons), employing the external beam of the synchrocyclotron. In this case two scintillators viewed by photomultipliers in double coincidence have been used as a detector in the position of focusing.

The analysis of all the results obtained experimentally shows that the instrument performs satisfactorily and in good agreement with the theoretical predictions.

ACKNOWLEDGEMENTS

The authors are pleased to express their appreciation to Prof. Svedberg for his interest in this work. They also want to thank Messrs. B. Hedin, G. Hanson and Å. Svanheden for their contribution to the construction of the instrument and Mr. G. C. Ghilardotti for help in the testing of the apparatus.

This work is part of a project supported by the Swedish Atomic Committee and CERN. One of us (A. L.) is a member of the Theoretical Study Division of CERN.

REFERENCES

(1) Cross, W. G. *Rev. Sci. Instrum.*, **22**, p. 717 (1951).
(2) Cotte, M. *Ann. Phys. [Leipzig]*, **10**, p. 333 (1938).
(3) Camac, M. *Rev. Sci. Instrum.*, **22**, p. 197 (1951).
(4) Garren, A. A., and Smith, L. UCRL 599 (Be University of California Radiation Labo 1950).
(5) Sternheimer, R. M. *Rev. Sci. Instrum.*, **23**, p. 629 (**24**, p. 573 (1953).
(6) Cartan, L. *J. Phys. Radium*, **8**, p. 453 (1937).
(7) Herzog, R. *Z. Phys.*, **89**, p. 447 (1934).

An instrument for measuring respiratory rates and volumes

By W. Nisbet, The Hannah Dairy Research Institute, Kirkhill, Ayr

[*Paper received* 14 *September*, 1955]

Fluctuating flow-rates, total flow volumes and the frequency of an alternating flow are measured by an instrument which has been used in respiration studies on the calf. The instrument consists of three units, one, a flow-sensing unit in the form of a fine mesh gauze used under laminar flow conditions; two, a magnetic induction manometer associated with an amplifier-detector and an oscillator and three, an electronic integrator.

The flow-rate/pressure relationship of the gauze is practically linear; ±3·5 l./s producing a pressure drop of ±1·25 mm of water. The amplifier-detector output is ±9 V, d.c. for a pressure of ±1·5 mm of water; the linearity of the complete manometer is within 1%. The integrator accuracy is normally ±2½% of full scale on any of eight ranges between 0–5 l. and 0–400 l.

Steady flow-rates and total flow are indicated on a 5 in. scale panel meter and instantaneous flow-rates on an external oscilloscope. Integration time is controlled by an electric clock movement and each flow alternation is recorded on an electromagnetic counter.

The need arose for an instrument which would measure the pulmonary ventilation rate of the bovine animal under a variety of environmental temperature and humidity conditions. It was necessary that the instrument should have the following characteristics.

(i) High stability.
(ii) Good accuracy over a range of 30 to 240 respirations/min.
(iii) Minimum resistance to respiratory flow. A maximum resistance of the order of 1 mm of water could be tolerated at a probable peak flow of 2 l./s.
(iv) High degree of linearity of response in the individual units of the complete instrument.
(v) Flow volumes shown instantly and provision for photographing respiratory flow patterns.
(vi) Simplicity of operation.

By modifying and combining the fine mesh gauze method of Silverman and Whittenberger(1) with the linear transducer of Tucker(2) and the electronic integrator of Pressey,(3) a suitable instrument was constructed.

METHOD

Variations in flow through a 300 mesh stainless steel gauze (supplied by Townson and Mercer Ltd.) are converted into pressure variations which are measured by a metal capsule manometer. A change of pressure across the capsule produces a change of voltage in an associated magnetic induction circuit, the output of which is amplified and then referred to a phase-sensitive detector. Provision is made for coupling an external oscilloscope to the detector which is also coupled to an electronic integrator. The integrator operates only on negative-going input signals, and in order that volumes of either inspirations or expirations may be integra manually positioned polarity reversing switch is in between the detector and the integrator. A block sche diagram of the complete pneumotachometer is show Fig. 1. Flow volumes are shown on a moving coil and integration time is controlled by a synchronous motor. The number of respirations is recorded by a ma counter actuated from a suitable point in the integrator

The components of the pneumotachometer are as foll

The flow-sensing unit. The design has been based o work of Silverman and Whittenberger.(1) A circular

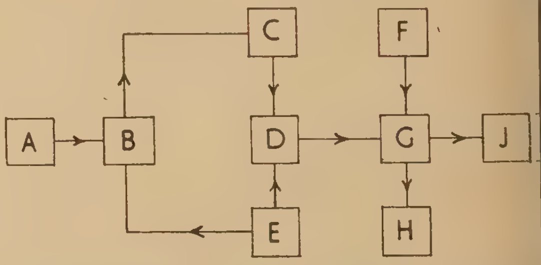
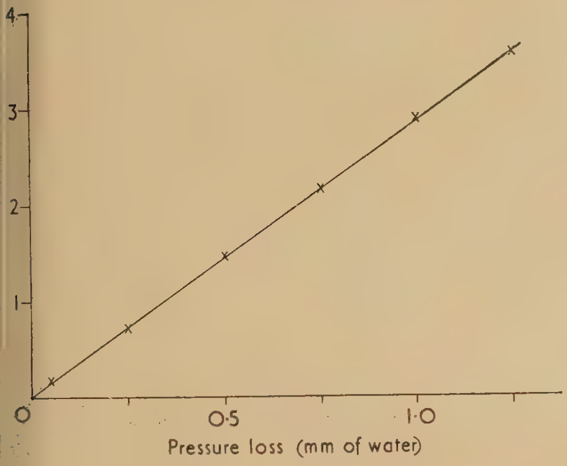


Fig. 1. Schematic diagram of pneumotachometer

A, flow-sensing unit; *B*, manometer; *C*, amplifier; *D*, ph sensitive detector; *E*, oscillator; *F*, clock; *G*, integrat *H*, counter; *J*, meter.

of 300 mesh gauze, $4\frac{1}{4}$ in. diameter, is cemented with Du to a Perspex annulus. The annulus has an outside diar of $4\frac{1}{2}$ in., an inside diameter of 4 in. and a length of $\frac{1}{2}$ in has ten equispaced internal peripheral ports or pressure of $\frac{1}{32}$ in. diameter coupling into a common man which has a lead-off pipe. The manifold is formed ıg a groove of $\frac{1}{8}$ in. width and $\frac{3}{16}$ in. depth in the outer nference of the annulus. The ports are then drilled ly and cleaned. They are positioned as close to the as possible. A $\frac{3}{16}$ in. wide strip of $\frac{1}{64}$ in. thick Perspex n laid around the groove and cemented to the annulus, 'orming the manifold.

complete unit clips on to the circular aluminium end- of a rubber mask worn by the animal. A rubber O- s half sunk into the end-piece to ensure an air-tight fit the flow-sensing unit. The mask has an inflatable r ring to stop leakages when fitted to the muzzle of the l and a baffle plate to prevent saliva spoiling the gauze. luction of the baffle plate produced no detectable change sensitivity or linearity of the flow-sensing unit. From



. 2. Typical calibration results for flow-sensing unit

2 it can be seen that the flow rate/pressure loss relation- is practically linear over the range 0–3·5 l./s. When the is reversed, no change can be detected in the sensitivity ıearity.

e transducer. The magnetic part of the manometer is l on work published by Tucker.$^{(2)}$ For the core, fifty-one ıetal E stampings (pattern No. 223 E by Magnetic and rical Alloys, Ltd.) are used. They are held together Araldite (by Aero Research Ltd.) and clamped, at outer limbs to the cross-bar *L* (see Fig. 3) by two flat 1 6 B.A. steel screws which enter the Tufnol crossbar ght angles to the laminations. The primary winding *P* sts of 750 turns of 44 s.w.g. enamelled wire wound on olin bobbin (by the Micanite and Insulating Co. Ltd.) h is held firmly to the laminations by Araldite. The ng coil *M* has sixty turns of the same type of wire ıd on a thin paper former, Durofix cement being used old the turns and former together. The coil supports, of Tufnol, are fixed to the coil *M* with Durofix and e capsule *H* with Araldite. Fixed to the cheek of the lin bobbin is another coil *N*, of forty turns of 44 s.w.g. ıelled wire. This coil, in conjunction with a phase 'ol R_1 in Fig. 4, cancels out the unwanted standing ge of the moving coil. Complete cancellation can be ed by adjustment of the cam shaft actuating knob *F* h determines the zero pressure position of the moving The gap between the shield *S* and the cam shaft *E* is d off with high vacuum grease. Thus, tubes *U* and *V* he only entries to the pressure-sensing capsule. This 's the tubes leading from the unit to be positioned side by side at the flow-sensing device so that undesired air disturbances have minimum effect on the transducer.

The capsule was obtained from a U.S. Air Corps type C2 rate-of-climb indicator and has a sensitivity of the order of 3×10^{-5} in. movement/mm of water. This movement per millimetre of water is comparable with the thermal expansion per °C of the other component parts of the transducer. Accordingly, the entire unit is encased in a 2 in. layer of cotton wool loosely packed in a wooden box, which is itself encased in another wooden box with 1 in. spacing all round filled with loosely packed cotton wool. With this thermal insulation zero drift is negligible under the experimental conditions described below. When in use the unit is placed in the observation room of a psychrometric chamber and is connected by a short length of flexible polyvinyl chloride tubing to the flow-sensing device situated inside the chamber; 20 ft lengths of screened coupling cable are used to allow remote positioning of the associated electronic equipment.

The oscillator, amplifier and detector. Conventional design procedure has been followed in the making of these units (see Fig. 4).

The oscillator consists of a Wien bridge generator, an attenuator, an amplifier and a cathode follower output stage. The sensitivity of the manometer is controlled by varying the output of the oscillator. Two controls R_{30} and S_2 are used, S_2 giving fixed attenuations of 0, $\frac{1}{2}$, $\frac{1}{4}$ or $\frac{1}{8}$th of the voltage developed across the combination of R_{30} and R_{31}. An extra position of S_2, giving no attenuation, is used in conjunction with R_{30} to give full-scale deflexion on the meter *G* when R_{44} is substituted for the transducer output circuit; this position of S_1 and S_2, which are ganged, is used for calibration pur-

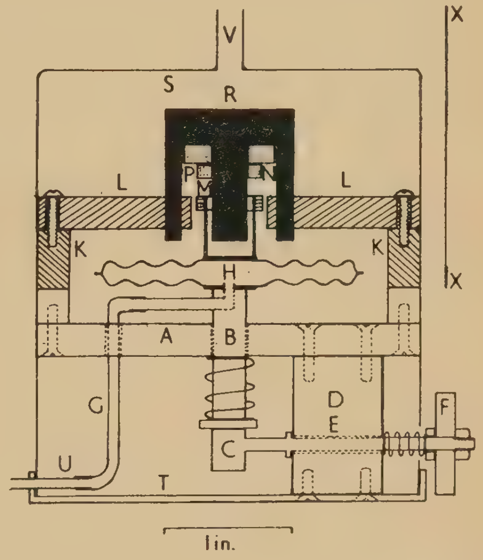


Fig. 3. Sketch of transducer with cut-away view at line *xx*

A, circular brass base; *B*, spring-loaded capsule positioning shaft; *C*, cam; *D*, stand-off bearing for camshaft; *E*, camshaft; *F*, capsule positioning knob; *G*, rubber tubing; *H*, capsule; *K*, brass rod; *L*, Tufnol cross bar $\frac{3}{4}$ in. wide; *M*, moving coil; *N*, fixed coil; *P*, primary coil; *R*, Mumetal lamination; *S*, magnetic shield; *T*, base for *S*; *U*, connexion to flow-sensing unit; *V*, connexion for capsule reference pressure.
The flying leads and terminals of the coils are not shown for the sake of clarity.

poses and the oscillator has an output of 10 V r.m.s. at this sensitivity. To maintain a steady phase reference voltage regardless of sensitivity, the phase reference valve V_4 is fed directly from the Wien bridge generator.

The manometer amplifier has three capacitance coupled stages with a 3 Ω negative feedback resistor R_{11} common to the first and last valve cathode circuits. Gain is such that 100 μV r.m.s. at the input to T_1 produces 4 V d.c. output at the detector. Transformer T_2 has a core of fifty interleaved Silcor 39E 0·015 in. laminations (by Magnetic and Electrical Alloys Ltd.) a primary of 1400 turns 38 s.w.g. enamelled copper wire and two symmetrical secondaries wound side by side, each with 350 turns of 38 s.w.g. enamelled copper wire.

T_3 is similar but with secondaries each of 420 turns. Phasing of the connexions of the secondary windings to the rectifiers MR_1 and MR_2 is such that at a given instant MR_1 receives the difference between a signal voltage and the phase reference voltage while MR_2 has impressed upon it the sum of the two voltages. With this circuit, b curvature of the rectifiers is overcome and linear det achieved with reversal of polarity of output for input reversal.

The detector output/pressure input relationship is lin within 1% up to 9 V on either positive or negative pres The basic sensitivity of the manometer is 6 V/mm of and may be reduced to 3, 1·5 or 0·75 V/mm of water b of the attenuator in the oscillator circuit. Thus, the value of the voltage to be integrated may be held at a venient level over a wide range of flow-rates. Advant taken of the extra ±3 V of output signal available fro detector by including a fine setting zero control R_{24}, w can shift the detector output voltage over the range with respect to earth (the chassis).

The integrator. The circuit of the integrator, which been modified from that of Pressey,(3) is shown in Fi Input signals from the phase-sensitive detector are p by the cathode follower V_1 to the linear amplifier V_2

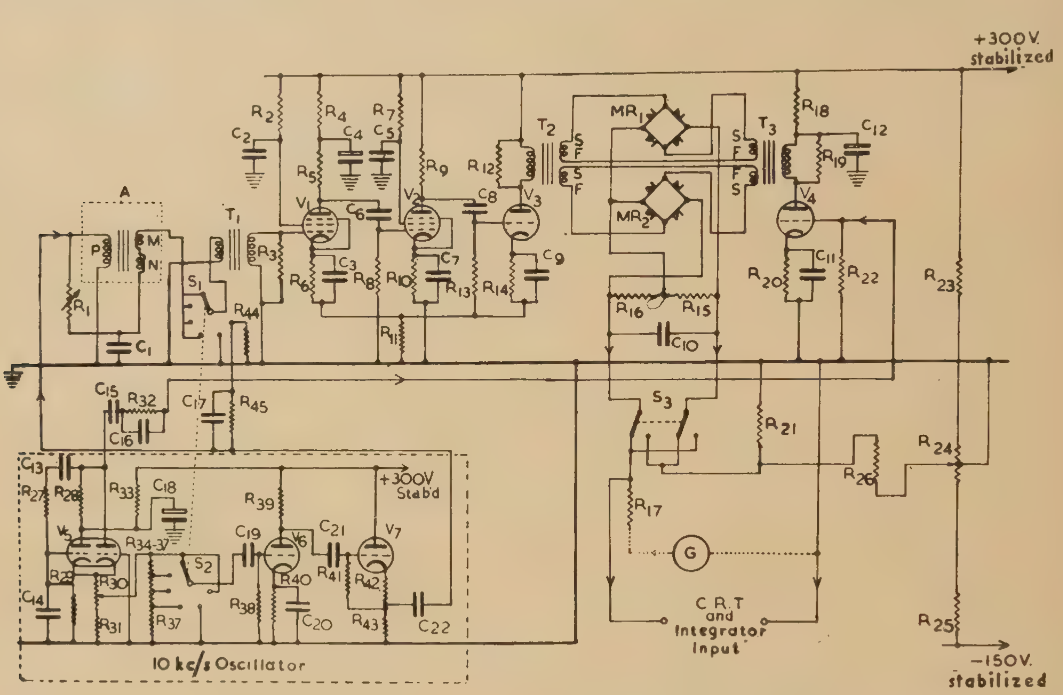


Fig. 4. Circuit diagram of oscillator, transducer and amplifier, and detector

R_1 = 50 kΩ wire wound potentiometer
R_2 = 680 kΩ
R_3 = 100 kΩ
R_4 = 33 kΩ
R_5 = 220 kΩ
R_6 = 2·2 kΩ
R_7 = 470 kΩ
R_8 = 680 kΩ
R_9 = 100 kΩ
R_{10} = 2·7 kΩ
R_{11} = 3 Ω constantan
R_{12} = 22 kΩ
R_{13} = 330 kΩ
R_{14} = 1 kΩ
R_{15}, R_{16} = 4·7 kΩ
R_{17} = 10 kΩ, 1% h.s.
R_{18} = 6·8 kΩ
R_{19} = 22 kΩ
R_{20} = 1 kΩ
R_{21} = 2·7 kΩ h.s.
R_{22} = 680 kΩ
R_{23} = 42 kΩ

R_{24} = 30 kΩ centre-tapped potentiometer
R_{25} = 15 kΩ
R_{26} = 56 kΩ
R_{27} = 15 kΩ
R_{28} = 6·8 kΩ h.s.
R_{29} = 15 kΩ
R_{30} = 500 Ω, w.w. potentiometer
R_{31} = 1 kΩ
R_{32} = 150 kΩ
R_{33} = 15 kΩ h.s.
R_{34} = 5 kΩ, 1% h.s.
R_{35} = 2·5 kΩ, 1% h.s.
R_{36} = 1·25 kΩ, 1% h.s.
R_{37} = 1·25 kΩ, 1% h.s.
R_{38} = 580 kΩ
R_{39} = 220 kΩ
R_{40} = 5·8 kΩ
R_{41} = 580 kΩ
R_{42} = 2·2 kΩ
R_{43} = 10 kΩ
R_{44} = 27 Ω constantan
R_{45} = 330 kΩ, 1% h.s.

C_1 = 1 μF
C_2 = 0·1 μF
C_3 = 0·1 μF
C_4 = 8 μF
C_5 = 0·1 μF
C_6 = 0·005 μF
C_7 = 0·1 μF
C_8 = 0·005 μF
C_9 = 0·1 μF
C_{10} = 0·5 μF
C_{11} = 0·1 μF
C_{12} = 8 μF
C_{13}, C_{14} = 0·001 μF mica
C_{15} = 0·1 μF
C_{16}, C_{17} = 47 pF mica
C_{18} = 8 μF
C_{19} = 0·001 μF
C_{20} = 0·1 μF
C_{21} = 0·001 μF
C_{22} = 0·1 μF

V_1 = EF37A
V_2 = EF91
V_3, V_4 = ½ 6SN7
V_5 = 6SN7
V_6, V_7 = ½ 6SN7

S_1 and S_2 = sensitivity and cali switches, ganged
S_3 = part of meter multi-s see text

A = electrical section of manom
M = moving coil
N = fixed coil
P = primary coil
G = 0–500 μA meter, first gra

T_1 = Bulgin LF 63 transformer
T_2 = signal transformer (for det text)
T_3 = Phase reference transform details see text)

MR_1, MR_2 = S.T.C. Uniplate rectifiers

Screening of the cables to A has been omitted for the sake of e *via* relay contact B_1 to the grid of the Miller integrator V_5. Screen voltages for V_2 and V_5 are stabilized by nd V_4 respectively. The output from V_2 is also fed igh the limiting amplifier V_8 and V_9 to the Schmitt er pair V_{10} and V_{11} which energize the Post Office relay *B*, allowing integration of a signal to take place only when nput to V_1 is of negative polarity. Relay *B* also operates lectromagnetic counter *T* which records the number of rations. For high respiratory rates relay *F* is used, geover being made by means of S_5. Relay *F* is a ens high speed relay and has only one set of contacts, he automatic counter is no longer operative.

nual control of the integrator is given by the ganged hes S_2 and S_3 which are shown in the "automatic ate" position. In this position relay *A* is energized *via* djustable time setting switch S_1 which is driven by the ronous clock motor *E*; S_1 may be set to give automatic ation over any preset time from 10 to 60 s, at the end ich it stops the motor by breaking contact A_2; at the same time A_1 returns V_1 grid to ground and A_3 operates the trigger pair so holding off the integrating relay *B*.

For longer integration periods the third position of S_2 "manual integrate" by-passes S_1 and integration may be stopped by pressing switch PB_1. Both PB_1 and PB_2 are used for setting up adjustments. Relay *D* is energized only when S_3 is switched to its first position, "reset"; the contacts of *D* then remove the integrating capacitor from the Miller circuit and charge it to a fixed value. The alternate contacts of S_4 are arranged in the manner of a guard ring, giving a choice of two integrating ranges with full-scale deflexion on the meter *G* corresponding to 0–5 and 0–50 l.; these basic ranges may be extended to 0–40 and 0–400 l. by appropriate use of the attenuator described above. Zero current through the meter *G* is maintained in spite of the standing anode current of some 20 μA, by means of a backing-off voltage derived from the contact potential of V_6; this circuit has negligible effect on meter accuracy. By means of a multiswitch, not shown, the meter *G* may also be used for

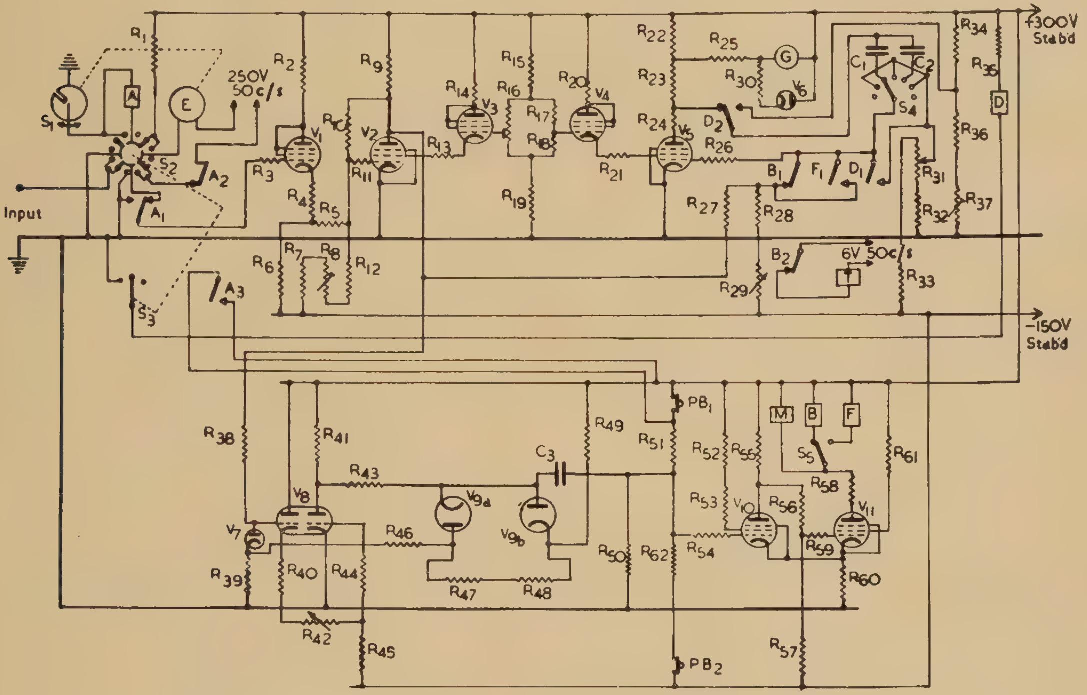


Fig. 5. Circuit of integrator with switches and relays in "automatic integrate" position

25 kΩ
39 kΩ
10 kΩ
3·9 kΩ
56 kΩ
100 kΩ
1·6 MΩ
1 MΩ potentiometer
120 kΩ
1·2 MΩ
1 kΩ
3·9 MΩ
$_4$ = 100 Ω
120 kΩ
200 kΩ potentiometer
18 kΩ
180 kΩ
56 kΩ
$_1$ = 100 Ω
1 kΩ, 1% h.s.
47 kΩ h.s.
100 Ω

R_{25} = 10 kΩ, 1% h.s.
R_{26} = 1 kΩ
R_{27} = 1 MΩ
R_{28} = 3·9 MΩ
R_{29} = 1 MΩ
R_{30} = 12 kΩ
R_{31} = 5 kΩ potentiometer
R_{32} = 3·9 kΩ
R_{33} = 220 kΩ
R_{34} = 7·5 kΩ
R_{35} = 82 kΩ
R_{36} = 220 kΩ
R_{37} = 100 kΩ potentiometer
R_{38} = 1 MΩ
R_{39} = 30 kΩ
R_{40} = 25 kΩ
R_{41} = 100 kΩ
R_{42} = 10 kΩ potentiometer
R_{43} = 1·2 MΩ
R_{44} = 2·2 MΩ
R_{45} = 100 kΩ
R_{46} = 33 kΩ

R_{47} = 4·7 kΩ
R_{48} = 4·7 kΩ
R_{49} = 120 kΩ
R_{50} = 1 MΩ
R_{51} = 1 MΩ
R_{52} = 100 kΩ
R_{53} = 100 Ω
R_{54} = 470 kΩ
R_{55} = 100 kΩ
R_{56} = 680 kΩ
R_{57} = 470 kΩ
R_{58} = 100 Ω
R_{59} = 1 kΩ
R_{60} = 470 Ω
R_{61} = 200 kΩ
R_{62} = 100 kΩ

C_1 = 1·1 μF
C_2 = 11 μF
C_3 = 0·01 μF

S_1 = adjustable time switch

S_2, S_3 = integrator control "reset auto-manual"
S_4 = range selector switch
S_5 = relay selector switch

PB_1 = integrator "hold-off" button
PB_2 = integrator "hold-on" button

A = relay controlling integrator
B = P.O. relay
D = resetting relay
E = synchronous clock motor
F = high speed relay
G = 0–500 μA meter, first grade
M = Metrosil disk
T = electromagnetic counter

V_1–V_5 = EF91
V_6, V_7 = EA50
V_8 = 6SL7
V_{9a}, V_{9b} = EB34
V_{10} = EF91
V_{11} = 6V6

other purposes, including monitoring and displaying flow-rate and pressure.

Power supplies. All of the units derive their power from a conventional series parallel 300 V 120 mA stabilized supply.

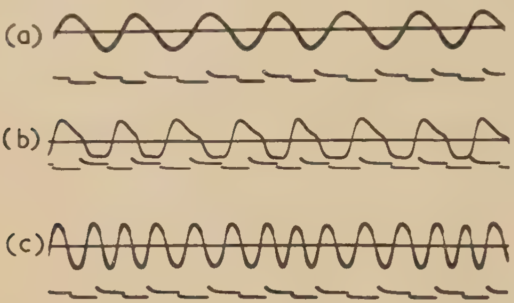


Fig. 6. Typical flow-rate waveforms

(*a*) Calibrating pump.
(*b*) Ayrshire bull calf, 20° C environment.
(*c*) Same calf, 40° C environment.
Expiratory flow above zero line. 1 s time markers.

A neon stabilized supply is also used for the integrator and to adjust the d.c. level of the output of the detector. Both power units are fed by a constant voltage transformer which also stabilizes all valve heaters.

CALIBRATION

A spirometer was used to check the accuracy and reproducibility of indication of total flow. As a further check, with known steady flow-rate conditions, a gas meter was used. In an attempt to simulate air flow in respiratory action, for further calibration purposes, an air pump of 940 ± $0 \cdot 5$ cm^3 swept volume, with a speed of 30 rev/min and a sinusoidally varying stroke was constructed. In all three conditions of flow, the total volumes indicated agreed to within ±2½%.

The flow sensing unit fitted to the air pump was subjected to a variety of humidities and temperatures in the range of 15 to 40° C and it was found that calibration was not noticeably affected by the consequent air viscosity changes and alterations of the dimensions of the gauze.

OPERATION

A warm-up period of one hour is allowed. In th few weeks of operation, working levels of V_2 and V_8 i integrator circuit had to be adjusted almost daily, bu circuits then settled to a stability that required on occasional adjustment.

With normal room temperatures, drift of the trans zero is equivalent to a pressure change of $0 \cdot 1$ mm of over one hour. In experimental use, pneumotacho readings are taken for a period of 1 min every 10 min, w zero and calibration check with the air pump before after each minute of operation. Drift in this case is negli

Under conditions of zero input, as established by meter *G* to indicate zero output from the detector integrator zero drift is barely detectable over 180 s of ope time on the most sensitive range.

RESULTS

Typical results are shown in Fig. 6. The waveform c calibrating pump, stroke 940 cm^3, speed 30 rev/min, is s in Fig. 6(*a*) and the respiratory pattern of an Ayrshire calf in normal environment can be seen in Fig. 6(*b*) the effects of environmental heat stress on the same cal shown in Fig. 6(*c*).

Data obtained from a series of experiments on Ay bull calves will shortly be published elsewhere.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. W. R. Beakley, now the Ministry of Supply, for his assistance in this work. is also indebted to Dr. J. Bligh for his design of the r mask.

REFERENCES

(1) Silverman, L., and Whittenberger, J. A. *A Cli Pneumotachograph—Methods in Medical Rese* Vol. 2, p. 104 (Chicago: The Year Book Publishers 1950).

(2) Tucker, M. J. *Electronic Engng*, **24**, p. 420 (1952).

(3) Pressey, D. C. *Electronic Engng*, **24**, p. 112 (1952).

A logarithmic megohmmeter

By P. Hariharan, M.Sc., A.Inst.P., and M. S. Bhalla, M.Sc., National Physical Laboratory of India, New Delhi, India

[*Paper received* 29 *September*, 1955]

An instrument is described which reads resistance values from 1 to 10^5 MΩ on a single, approximately logarithmic scale. It is reliable, easy to operate, and immune to damage by accidental overloads.

Ohmmeter circuits using a vacuum tube voltmeter or a sensitive galvanometer as the indicating element are usually employed for the measurement of high resistances and for insulation tests. Such circuits have the drawback that only a comparatively small range of resistance values can be read, with reasonable accuracy, at a given sensitivity setting. Further, at high resistance values, there is a risk of damaging the meter if the resistance under test breaks down. The instrument described in the present paper avoids these difficulties by utilizing an ohmmeter circuit based on the logarithmic grid current–plate current characteristics triode vacuum tube.(1)

CIRCUIT DETAILS

Fig. 1 is a circuit diagram of the instrument. logarithmic amplifier uses a type 6F8 double triode which is particularly suited for this purpose, since its metrical construction permits the use of a balanced circu while the leakage resistance between the grid of the on, which is connected to the top cap, and the cathode the order of 10^6 MΩ. This section is used in the actual meter circuit, while the other section serves to cancel he effects of heater voltage fluctuations.

ıe plates of the type 6F8 tube are directly coupled to the of a balanced cathode follower V_2 which drives a 0 µA meter. The meter zero is set by means of the ble resistor R_7 and the meter sensitivity can be adjusted eans of the variable shunt R_{13}.

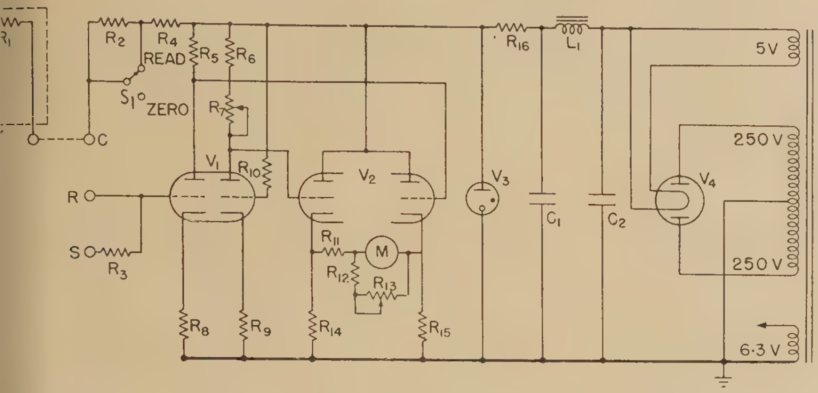


Fig. 1. Circuit diagram of the instrument

R_1 = 2 MΩ ± 1%
R_2 = 1 MΩ ± 1%
R_3 = 10 kMΩ
R_4 = 0·5 MΩ ± 1%
R_5 = 100 kΩ
R_6 = 68 kΩ
R_7 = 100 kΩ
R_8, R_9 = 10 kΩ
R_{10} = 1·5 MΩ
R_{11} = 20 kΩ
R_{12} = 300 Ω
R_{13} = 250 Ω
R_{14}, R_{15} = 10 kΩ
R_{16} = 5 kΩ w.w.

C_1, C_2 = 16 µF
L_1 = 8 H
V_1 = 6F8G
V_2 = 6SN7
V_3 = VR105
V_4 = 5Y3
M = 0–100 µA
B = 400 V

full wave rectifier V_4 stabilized by a voltage regulator V_3 supplies the plates and provides a test potential of / at the terminal C. The resistance under test is cond between the terminal C and the terminal R, which is ected to the top cap of the 6F8 tube. A 0·5 MΩ or in the supply lead limits the short circuit current to oximately 200 µA, in case the resistance under test s down.

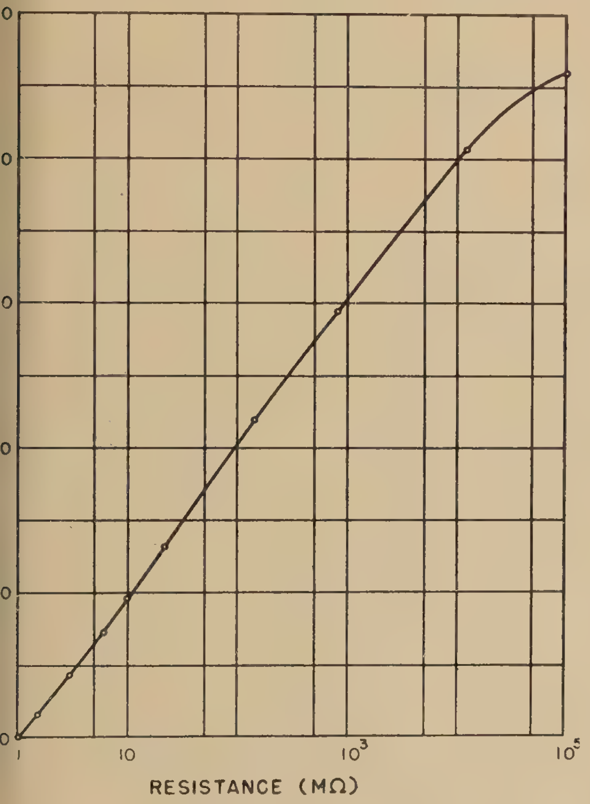


Fig. 2. Calibration curve of the instrument

CALIBRATION

In normal use, the scale of the instrument is checked by means of two standard resistors, R_2 and R_3. The meter zero is first set by adjusting R_7, after moving S_1 to the "zero" position and connecting terminal C to terminal R. Switch S_1 is then moved to the "read" position, terminal C is connected to terminal S, and R_{13} is adjusted so that the meter current is 80 µA.

A typical calibration curve for the instrument, with these settings, is shown in Fig. 2. The scale is closely logarithmic from 1 MΩ to a little over 10^4 MΩ. With a calibration curve, an accuracy of ±2% is possible over most of this range and resistances up to 10^5 MΩ can be read on the same scale.

INSULATION TESTS

For insulation tests in which a test potential of 500 V is specified, the multiplier unit shown at the left of Fig. 1 is useful. This contains miniature batteries connected to give a total of 400 V, in series with a 2 MΩ resistor. The negative terminal of this unit is connected to C, and the test specimen is connected between C' and R. Since the multiplier unit is in series with the internal 100 V supply and the 0·5 MΩ resistor R_4, a test potential of 500 V is obtained, with a total series limiting resistance of 2·5 MΩ. Except for the resistance values being multiplied by a factor of five, the calibration curve of the instrument remains unchanged. Insulation resistances up to 10^6 MΩ can be measured, and, since the current drawn from the batteries is only a few microamperes, their life is quite reasonable.

PERFORMANCE

Actual use in routine tests shows that the logarithmic scale results in a considerable saving in time and makes the instrument virtually foolproof. This feature is particularly useful in testing the insulation resistance of capacitors, since they are charged quite rapidly, at the normal setting, with no risk of overloading the meter.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. W. M. Vaidya for his interest in this work and Dr. K. S. Krishnan, Director, National Physical Laboratory of India, for permission to publish this paper.

REFERENCES

(1) Russell, J. *Rev. Sci. Instrum.*, **8**, p. 495 (1937).
(2) Attree, V. H. *J. Sci. Instrum.*, **32**, p. 41 (1955).

Laboratory and workshop notes

Simple high-pressure closures and electrodes

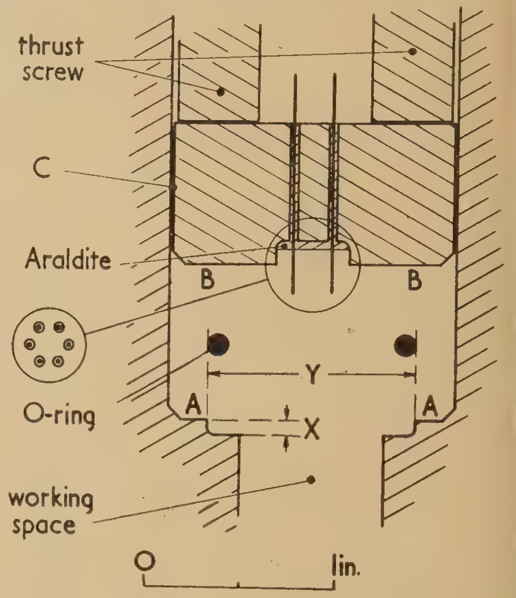
By D. GUGAN, B.Sc., Queen Mary College, University of London

[*Note received* 3 *August*, 1955]

In work at high pressures much time is spent in maintaining the specifically high-pressure part of the project in order; the seals and electrodes described here have been developed with this in mind and have led to a considerable saving in both experimental and workshop time. They are being used regularly up to pressures of 5000 atm in a system employing kerosene as the transmitting fluid, and have been tested up to 10 000 atm in the same apparatus.

O-rings are used in the closures as shown in the figure (see also Jacobs*). The rings are held in a recess, the dimensions of which are chosen such that X is about three-quarters of the thickness of the ring and Y is slightly less than the outer diameter of the ring; when the ring is in its seating it is held tightly but is not pinched. The mating surfaces A–A, B–B, are turned accurately perpendicular to their common axis and are finished as smooth as possible; the ring is lightly greased and the seal is made by tightening the thrust-screw until the mating surfaces meet tightly and compress the ring into the recess. The fact that the clearance at C can be large is particularly convenient in assembling and dismantling the high-pressure apparatus. This closure will support pressures above 9000 atm if the dimensions X and Y are properly chosen, but the considerable initial extrusion of the O-ring in the small gap between the mating surfaces makes the seal liable to sudden failure at these high pressures. These seals have been in regular use up to pressures of 5000 atm and, provided that they are renewed fairly often, they are very reliable. O-rings of various sizes have been used and quite large diameters can be satisfactorily sealed by this method. The rings used have all been moulded elastomer vacuum O-rings, by W. Edwards and Co. Ltd.

In some experiments it is essential to have multi-lead electrodes of high insulation, about $10^{10}\,\Omega$; a typical figure for the resistance of a Bridgman type electrode is $10^{7}\,\Omega$. Because of this difference and because of the great difficulties in making multi-lead Bridgman electrodes it was decided to try sealing leads in with Araldite. Lazare† had some success using a similar method but was restricted to lower pressures. The method of construction is shown in the figure; the metal support is made of hardened steel. The size of the holes is about 1 mm for a 22 s.w.g. wire and for smaller wires in the same proportion. This gauge wire is quite suitable; finer gauge wires might support higher pressures but the extra difficulties in using them have made them less reliable. To ensure that the insulating properties will be satisfactory the wires are given a thin coat of Araldite before they are inserted in the holes. A successful method of doing this is to heat the wires electrically and to rub Araldite on from a stick; after the wires have been partially cured (for about 10 min at 200° C) the coat should be thin and fairly uniform. The support is prepared by heating it to about 140° C (an air-blower is convenient for this) and Araldite powder is put in the recess; it is allowed to run down into the holes and will wet them if they are clean. While the Araldite in the holes is still molten the wires are pushed into position, wetted by the Araldite, and then held fixed in position while the whole support is given the full hardening treatment for the Ara
this consists of holding it at 200° C for one hour and
allowing it to cool slowly to room temperature. On in
tion the Araldite should be smooth, uncracked, and in
contact with the metal parts. If the electrode leaks sli
when first tested it is often possible to remedy this by app
quickly a fairly high pressure; the leak then appears to
permanently. If the electrode leaks badly the Araldit
be burnt out by holding the support at about 350° C



Assembly of the electrodes and the O-ring seal in t
high-pressure vessel

few hours; the support may be used again after it has
cleaned. The insulation resistance is about $10^{11}\,\Omega$ an
highest pressure at which tests have been made (for a
test only) is 9700 atm. The wires sealed-in need not
great mechanical strength. Thermocouple wires, for exan
have been sealed directly into the test vessel, enabli
considerable improvement to be made in measurement
temperature in the high-pressure system. The only failu
normal work was after about three months use; the fa
was at about 6000 atm but was preceded by a very obv
leak and caused no trouble or danger.

The author wishes to thank Prof. G. O. Jones for
interest, Mr. W. A. G. Baldock for his careful work in
machine shop and the Department of Scientific and Indus
Research for the award of a maintenance allowance.

---

* JACOBS, I. S. *Phys. Rev.*, **93**, p. 994 (1954).

† LAZARE, F. *J. Phys. Radium*, **14**, p. 213 (1953).

A simple gas valve

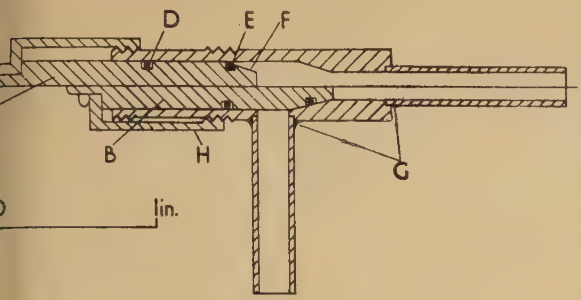
By J. FULLER, Cavendish Laboratory, University
Cambridge

[*Note received* 8 *August*, 1955]

The valve illustrated in the figure has been used in
laboratory with excellent results, both for high vacuum
and for pressures up to two or three atmospheres. Tho
compact, the valve in the open position offers little resista
to gas flow. It has few component parts and lends itse
quantity production.

To obtain adequate sealing by the O-rings (by G. Ar
and Co. Ltd.) the finish of the bore and the tapered seat m

od and to ensure this a special reamer should be made e purpose. A lead of about 20° should be made at the nce of the body to permit easy insertion of the O-rings.



Diametral section of valve

alve open position; *B*, valve closed position; *C*, securing ng; *D*, O-ring, No. 103, groove 0·053 in. deep, 0·080 in. e; *E*, O-ring, No. 101, to protrude 0·020 in.; *F*, taper ni-angle 14°); *G*, hard-soldered joints; *H*, knurled sleeve.

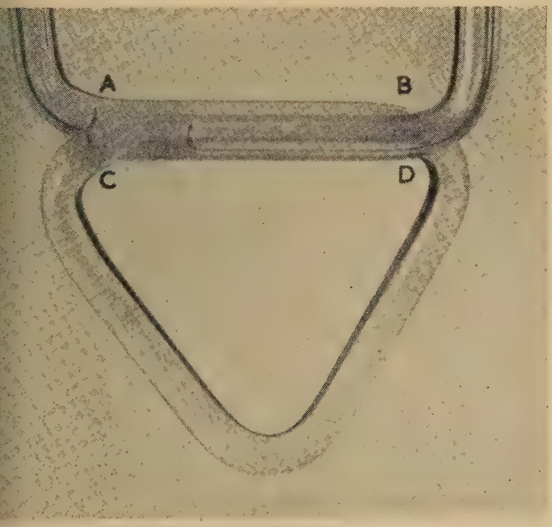
e figure shows the smallest version of the valve which een made but larger ones (up to $\frac{3}{8}$ in. bore) have been successfully, the limiting factor being the force necessary en (or close) the valve against atmospheric or other ure.

A sensitive null-point manometer

J. P. Berry, Ph.D.,* The British Rubber Producers' Research Association, Welwyn Garden City, Herts

[*Note received* 30 *November*, 1955]

nanometer described below was developed for use in a ant pressure oxygen absorption system where a normal ne oil U-tube manometer was found to be insufficiently ive. It combines extreme sensitivity at the null point n overall stability to fortuitous pressure variations.



Sensitive null-point manometer

manometer is constructed from thin wall semi-capillary g (3·5 mm outer diameter, 2 mm inner diameter) bent he shape illustrated in the figure. It is important that rtions of the arms *AB* and *CD* are parallel and in the horizontal plane. Sufficient out-gassed silicone fluid (DC702 by Midland Silicones Ltd.), is introduced to fill the manometer from some point on *AB* to an approximately corresponding point on *CD*.

Any movement of one meniscus results in a corresponding movement of the other meniscus, their relative positions being maintained over the horizontal part of the manometer. If the travel of the menisci is truly horizontal only viscosity and surface tension forces have to be overcome and no change in pressure occurs. Thus over this range the manometer is extremely sensitive. Outside this range, however, the action is that of a normal U-tube manometer with its attendant stability to finite changes in pressure.

Miniature diffraction cameras for micro-focus X-ray units

By J. B. Finean, Ph.D., Department of Pharmacology, University of Birmingham

[*Note first received* 25 *July, and in final form* 25 *August*, 1955]

In order to utilize effectively the X-ray beam provided by micro-focus X-ray units it has been necessary to develop special miniature diffraction cameras. Two cameras (a low-angle vacuum camera and a wide-angle rotating crystal camera) in current use in this laboratory (Fig. 1) have been designed for use with the Hilger micro-focus X-ray unit. Both cameras are mounted on the adjustable supports (see Fig. 1) supplied by the unit makers for Brindley-type cameras.

The low-angle vacuum camera makes use of the arrangement described in an earlier publication* of mounting two sets of slits at right angles to each other. The slits are mounted on separate inserts which are spring-loaded on to adjustable holders in such a way that they can be removed and replaced without disturbing the alinement of the collimating system. This is a great advantage in lining up the collimating system as a whole, and also in locating the beam stop and the specimen. All parts of the system are housed in a vacuum-tight box of aluminium and Tufnol which measures 8 by $2\frac{1}{2}$ by $2\frac{1}{2}$ in., and all adjustment controls are accessible from above. The lid (which carries the connexion to the vacuum pump) is pressed down on to a continuous rubber gasket around the top of the box.

Three slit holders are provided, though with the micro-focus X-ray tube it has been found necessary to use only two of them.† The first one (non-adjustable) is at the entrance to the camera and outside the vacuum chamber. It can be carried to various distances from the main body of the camera on vacuum-tight extension tubes and may be used in conjunction with one or both of the adjustable holders inside the box so as to allow the maximum specimen-film distance to be achieved. When used with a large focus X-ray tube this first collimator serves to select a part of the beam for collimation by "defining" and "guard" apertures inside the main box. The two adjustable slit holders are provided with lateral and vertical movements and are themselves mounted on a bar running along the bottom of the box and adjustable along it by means of long screws operated from outside the box. The specimen holder is mounted in a slot very close to the holder for the guard apertures. The film holder and the frame carrying the beam stop are located in sets of closely spaced slots cut in the walls of the box. A number of such sets of slots are provided so as to permit a variation of specimen-to-film distances. The air pressure in the small vacuum chamber can be reduced to $\frac{1}{2}$ mm of mercury in less than a minute. The front of the camera is located on the adjustable support and the back of the camera is provided with two adjustable legs, located on a support which is mounted on an optical bar running along the table of the X-ray tube. This too provides lateral and vertical movement so that the camera can be readily adjusted to the direction of throw of the X-ray beam.

---

* Now at The University of Akron, Ohio, U.S.A.

* Finean, J. B. *J. Sci. Instrum.*, **30**, p. 60 (1953).

† Finean, J. B., and Millington, P. F. *Trans Faraday Soc.*, **51**, p. 1008 (1955).

The wide-angle (rotating crystal) camera also takes advantage of the mounting provided for the Brindley-type camera. The centre of the adjusting column is drilled to take a $\frac{1}{4}$ in. diameter spindle (2*a*, Fig. 2) which is held firmly in a ball-race (2*b*) set in the upper end of the column. A second ball-race (2*c*) is located in the base of the column, and made to fit the spindle closely while at the same time allowing it to be pulled through on the action of the vertical adjusting screw (2*d*). A gear wheel (2*e*) is attached to the portion of spindle projecting below the mounting and the spindle rotated by means of a synchronous motor (1 rev/min) mounted on the optical bar attached to the table of the X-ray unit. On the upper end of the spindle is mounted a small goniometer head (2*f*) carrying the crystal to be examined. The other parts of the camera are mounted independently on the X-ray tube itself. A block (1*a*), provided with beam cut-offs (1*b*) sliding in horizontal slots, is clamped around the X-ray tube, and the camera hangs on a single pivot (3*a*) from a V-groove (1*c*) in a fitting attached to the top of the block. Two adjusting screws (3*b*) bearing against the vertical face of the block serve to adjust the camera to the direction of the X-ray beam, and when this is achieved the camera is cla firmly in position by means of a yoke (1*d*) fitting ove arm (3*c*) of the camera close to the pivot. The collim (3*d*) are either lead glass capillaries or permanently-a pinhole apertures. The specimen holder projects throu hole in the bottom of the camera (3*e*) and the specim observed through a telescope which is mounted independ on the optical bench. The 2 cm diameter film holder (positioned on the horizontal platform (3*e*) on the holder, and its accurately machined face (4*b*) fits close the front (3*f*) of the camera. It is adjusted laterall screws (3*g*) so that the X-ray beam passes exactly throug centre of the cylinder. The beam stop (4*c*) is mounted o film holder and projects through a hole in the film.

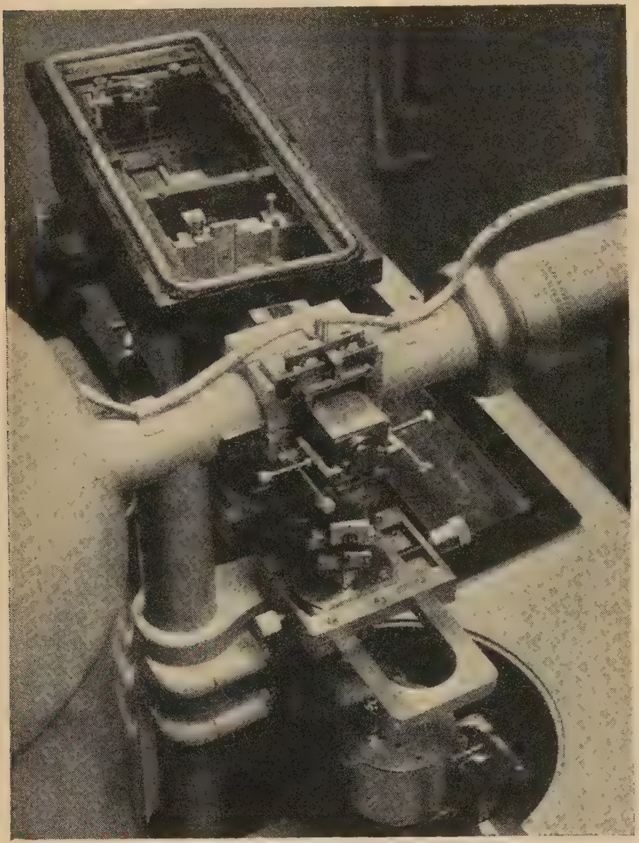


Fig. 1. Micro-focus X-ray tube with low-angle and rotating crystal cameras in position

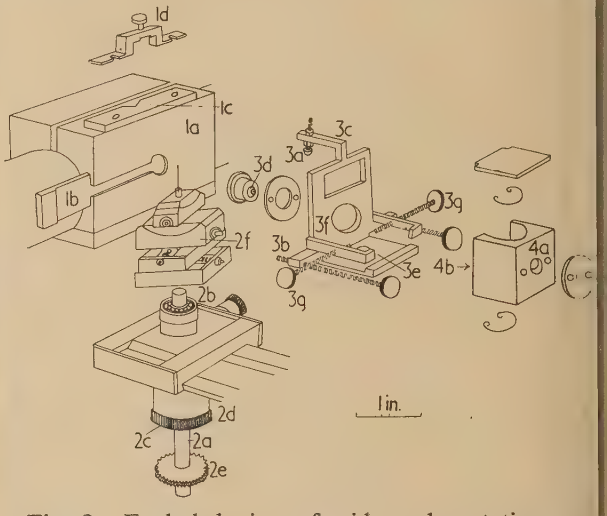


Fig. 2. Exploded view of wide-angle rotating crys camera

In setting up a specimen, the camera is adjusted to gi X-ray beam travelling in a direction at right angles to spindle, and is then clamped in position. A fine wire o of fluorescent material is mounted on the goniometer and adjusted until it rotates accurately on itself. The w specimen mount is then adjusted laterally until the beam passes through the specimen (detected by decrea intensity of the beam or by fluorescing of the rod). A cr is now mounted on the goniometer head and when th accurately centred by rotation and observation in the teles it will also be alined with the X-ray beam. In order to en that the crystal is in the exact centre of the cylindrical it is necessary to take rotation photographs of the cr and to adjust the film holder laterally, and perhaps also specimen mounting towards or away from the X-ray until the required symmetry of the diffraction patte obtained.

With this type of camera, the specimen is brought to w 3 cm of the focal spot of the micro-focus X-ray tube and whole of the focal spot is utilized by the collimating sys The output of the tube is thus used to greatest effect, and exposure times are appreciably lower than those require similar specimens examined with conventional tubes cameras, where the distances involved are greater and a portion of the output of the X-ray tube utilized. The advantage of this camera is that it facilitates the stud substances available only in micro-crystalline form, a situa which frequently arises in dealing with biological system biologically important substances.

Correspondence

ing electrode unit for measurements of the electric strength of insulating liquids

npts to measure the "intrinsic" electric strength of an
ting liquid entail the use of highly polished electrodes
a liquid free from impurities. Even if the test gap is
cted so that the energy dissipated in the gap during
down is limited to little more than the energy stored in
lectrode capacitance, the electrode surfaces deteriorate
iently to cause a lowering of the measured electric
gth with successive breakdowns.* Fresh electrode
ces are needed for each breakdown measurement and to
dismantling, cleaning and reassembling the test cell
each breakdown, it is convenient if the electrodes can
tated. In an investigation at the University of Birming-
it was required that the electrodes could be rotated from
de the test cell, that the unit should be simple to clean
ssemble and that the variation of the electrode separation
d be less than 10% with rotation and less than 3%
g a measurement. For an electrode separation of
in., these conditions are satisfied with the apparatus
n in Fig. 1.

ch electrode is a ¼ in. diameter stainless steel ball
ically butt-welded to a 0·08 in. diameter stainless steel

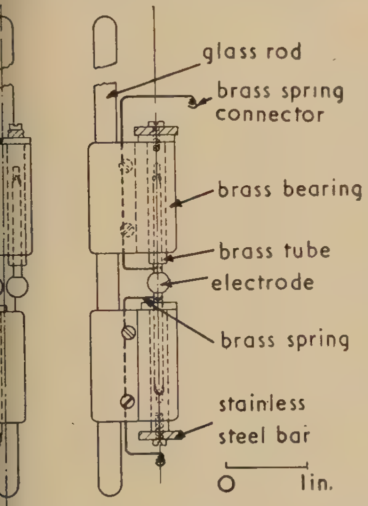


Fig. 1. Rotating electrode unit

k. (Accurate welding is facilitated by grinding two
lel flats on the electrode and using the jig shown in
2.) The shank is a push fit in a brass tube which is
able in a brass bearing. The small stainless steel bar
hed to the brass tube allows the rotation to be produced
magnetron magnet held outside the test cell. Two such
nblies are clamped on a glass rod so that the electrodes
ide by side and the required distance apart. The slack
e bearings is less than 0·0003 in., but as a precaution a
spring presses on each shank. The electrostatic force
traction arising from a d.c. stress of 430 kV/cm applied
e electrodes immersed in *n*-hexane alters the electrode
ation by less than 0·0003 in. The eccentricity of each electrode surface is less than 0·002 in., and by arranging this error to be in the same direction for each electrode, the total variation in the electrode separation with rotation of the

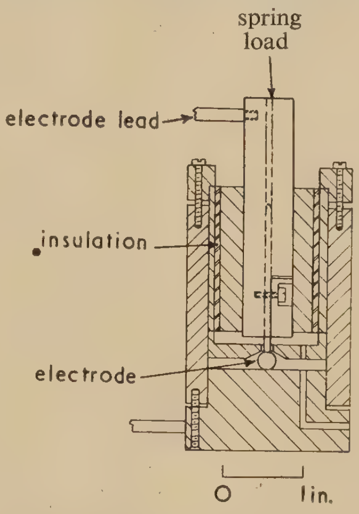


Fig. 2. Sectional view of the electric welding jig

electrodes is less than 0·001 in., i.e. less than 10% of the normal electrode separation of 0·01 in.

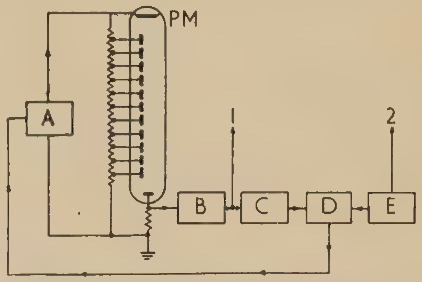
Electrical Engineering Dept., University of Birmingham. — A. Powell
Electrical Research Association, Perivale, Middlesex. — K. H. Stark

---

* Stark, K. H. and Higham, J. B. *E.R.A. report*. To be
hed.

Modifications of photomultiplier characteristics by dynode voltage control

In the paper by Dr. E. M. Deeley published in the July 1955 issue of this *Journal* (p. 263), I was interested to note his use of a variable dynode supply voltage to control the characteristics of a photomultiplier tube. I used a similar feedback control system to equalize the characteristics of two photomultipliers in the particle counter employing a flying-spot microscope which was developed at the Mullard Research Laboratories for the National Coal Board and exhibited at The Physical Society's Exhibition in 1954.



Video channel of particle counter

A, controlled r.f. e.h.t. supply; *B*, video amplifier; *C*, peak diode rectifier; *D*, voltage comparator; *E*, common reference potential source; *PM*, photomultiplier, type 6260; 1, channel 1 video output; 2, to channel 2 comparator.

The flying-spot microscope used two light paths with photomultipliers as detecting elements. For reliable operation the photomultipliers had to possess equal light sensitivities. This was achieved by constructing each photomultiplier and amplifier chain as shown in the block schematic diagram. Both photomultipliers received transmitted light from a projected spot scanning the same microscope slide. "Peak white" diode detectors were therefore used whose output voltages were compared with a common reference potential. Amplified difference voltages were fed back to control the e.h.t. supplies for the respective dynode chains thus varying the photomultiplier gains to keep the "peak white" signals equal to the common reference potential.

This system gave a high degree of stability and output signals which were independent of variations in scanning spot brightness, photomultiplier gain, amplifier gain and e.h.t. supplies.

Mullard Research Laboratories,
Cross Oak Lane, Redhill, Surrey.
D. S. HOBBS

The dynode circuit employed in the integrating microdensitometer is a modification of that originally described by Sweet (see paper) for the generation of a voltage proportional to the logarithm of light intensity.

Mr. Hobbs uses the dynodes for a somewhat different purpose. He applies to the flying-spot microscope a principle that has been used by several workers in the field of microspectrophotometry.

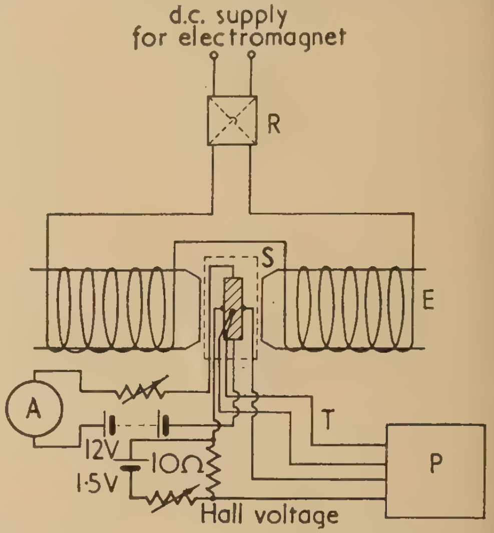
Wheatstone Physics Laboratory,
King's College, University of London.
E. M. DEELEY

A simple apparatus for recording the variation of Hall coefficient with temperature

In the preparation of semi-conductors such as indium antimonide, routine measurements of Hall coefficient are a useful check of the quality of the product. For this purpose measurement at room temperature only is not sufficient because much of the material becomes intrinsic below room temperature. A measurement at a fixed low temperature, such as liquid air, would be sufficient for obtaining the impurity concentration in this material, but it is also necessary to know the mobility ratio, which can only be found by measuring the variation of Hall coefficient with temperature between liquid air and room temperature. Using the method described here it is possible to measure the complete curve in about twenty minutes, which represents a considerable saving in time compared with manual plotting.

The arrangement of the apparatus is shown in the figure. The sample, with suitable connexions welded or soldered to it, is placed in a small Dewar flask between the poles of an electromagnet. A constant direct current is passed through the sample and the Hall probes are connected to one channel of a two-channel electronic recording potentiometer. The second channel of the recorder is connected to a T1–T2 thermocouple (the British equivalent of chromel–alumel) attached to the sample. The sensitivity of the recorder is about 5 mV full scale. A voltage developed across a small resistanc eis injected in series with the Hall effect probes and is adjusted so that the recorder, when connected to the Hall circuit, reads about half-scale deflexion when the magnet is switched off. The magnet is switched on and reversed periodically using mercury relays excited by means of a timing unit operated from a synchronous motor. This is geared so that the magnet current is reversed every fifteen seconds. The current through the sample is adjusted so that when the magnet is switched on, a Hall voltage is produced which deflects the recorder either to the right or the left of the setting produced by the constant injected voltage.

When the magnet reverses, the recorded deflexion change to the opposite side and so a square wave patter be plotted on the chart. The amplitude of the square is equal to twice the Hall voltage. If the temperature sample is changing at a suitable rate, the change in coefficient will be indicated by a change in the amplitu the square wave. Zero Hall coefficient and the chan



Schematic diagram of recording Hall effect appara
Part of circuit enclosed by a dotted line is placed ins
the Dewar flask

A, specimen current (mA); *E*, electromagnet; *P*, two-chan recording potentiometer; *R*, automatic reversing switch; specimen; *T*, thermocouple.

sign are clearly indicated by the pattern drawn on the c While the Hall coefficient is being recorded, the second cha of the recorder is recording the temperature. It has found convenient to arrange the selector switch on the rec so that four-fifths of its time is spent recording the coefficient and the rest recording the temperature. placing the sample in a tailed Dewar vessel of about 150 total capacity, it is found that the liquid air will boil and the specimen warm to room temperature in about tw minutes. This rate of warming is convenient for measu the curve and is sufficiently slow to prevent large tempera gradients appearing across the crystal.

The method described has proved very convenient making routine measurements on indium antimonide. suitable re-arrangement of the specimen holder, this techn has also been applied to measurements above room temp ture where the rapid recording of results is often neces to circumvent changes produced by disassociation at temperature. The method is particularly suitable for use comparatively massive single crystals, for the rate of warm up is determined by the thermal capacity of the crystals cannot be increased to the high rates possible with evapor films. The sensitivity of the method is determined by of the recorders available. Using an instrument of 1 mV scale deflexion a Hall voltage of 100 μV can be measure a few per cent. Voltages of this magnitude can usuall obtained from specimens with Hall coefficients of a 1 cm^3/C.

Acknowledgement is made to the Controller H Stationery Office, for permission to publish this paper.

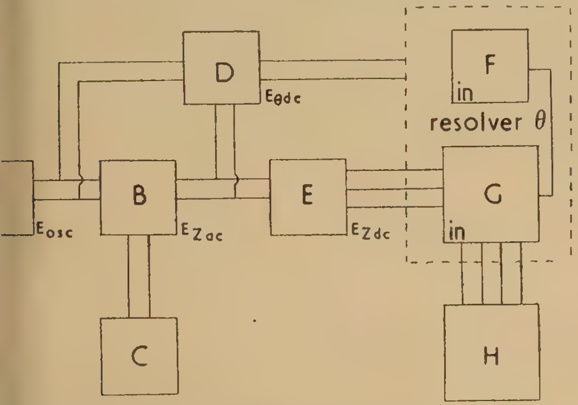
Radar Research Establishment,
Malvern, Worcs.
E. H. PUTL

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved icts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

matic impedance plotter. Chesapeake Instrument Corporation, Shadyside, Maryland, U.S.A.

impedance plotter is a device which plots automatically eries components of the complex impedance $Z = R + iX$ y electrical network, or electromechanical network, as a ion of a chosen parameter. For example, it will plot R e abscissa and $\pm X$ as the ordinate, with frequency or other variable as the parameter. The system can also ranged to plot either R or $\pm X$ as the abscissa with other variable, for example, temperature, as the ordinate. e figure shows, in schematic form, the principle of the ment. A signal generated in the oscillator is fed to "impedometer." This is a device which maintains a ant current through the unknown impedance by the s insertion of a resistor whose impedance is about 100 that of the unknown value. The variation of the ge drop across the unknown impedance is therefore ortional to its impedance. This voltage is amplified and erted to a direct one by means of the decade amplifier ectifier.



Schematic circuit of automatic impedance plotter

oscillator; *B*, impedometer; *C*, test sample; *D*, phase angle ter; *E*, decade amplifier rectifier; *F*, servo-input resolver; *G*, sin-cos potentiometer resolver; *H*, X-Y recorder.

e phase angle between the oscillator voltage and that s the unknown impedance is the phase angle of the own impedance. This is measured by means of a phase meter and its output is a direct voltage whose magnitude oportional to the magnitude of the phase angle. The direct outputs are therefore proportional to the total dance Z and the phase angle θ. The desired components $\sin\theta$ and $Z\cos\theta$. The required trigonometric operation rried out by means of a resolver consisting of a servo n for θ and a sine-cosine potentiometer. The arms of otentiometer are positioned by the magnitude of the θ l, and the Z signal is impressed across the potentiometer. outputs are therefore $Z\sin\theta = X$ and $Z\cos\theta = R$. two output, direct voltages from the sine-cosine tiometer are fed to the ordinate and abscissa inputs of Y recorder, and thus the pen is positioned at the co-ate point R, X. If now the frequency of the oscillator ied, the recorder pen will trace in the complex plane the of the vector impedance of the unknown impedance. e recorder is a Moseley Autograph XY recorder, which plots on standard 8½ × 11 in. graph paper. The zero can be located anywhere on the graph paper or suppressed. Calibration is readily accomplished by means of standards furnished with the instrument. The instrument operates over a range of 10 c/s to 100 kc/s and will deal with resistances between zero and 10 kΩ and reactances between ±10 kΩ. An accuracy of 2% is claimed.

Precision pulse oscilloscope. Newport Instruments Ltd., Newport Pagnell, Buckinghamshire.

An oscilloscope has been designed for precise measurements of the characteristic features of pulsed or transient waveforms. The instrument uses a high beam current cathode-ray tube having a blue screen of short persistence which gives a sharp, bright trace in full daylight. The stabilized high tension supply to the tube is adjustable in four steps from 1·8 to 3·6 kV.

The Y-amplifier is d.c. coupled with a gain of 1000 and a rise time of 0·04 μs. With full gain, the overall sensitivity is 200 mV/cm; an input attenuator provides eight attenuation ratios from ÷1 to ÷200. The amplifier is normally used in conjunction with a ×10 probe. An accurately calibrated Y-shift serves to measure the signal by backing it off at the amplifier input.

The time-base circuits are d.c. coupled and produce a linear 10 cm trace at maximum high tension or e.h.t. Nine calibrated sweeps are available with durations from ½ to 1000 μs. Slower sweeps can be obtained by connecting additional condensers to the terminals provided. The makers claim that linearity is better than ½% for sweeps longer than 5 μs. Normally triggered, but synchronized, free-running facilities are provided by an internal pulse generator providing 2 μs pulses with a calibrated repetition frequency. The X-shift control is directly calibrated in microseconds to an accuracy of 1%. An additional facility is a brightness marker strobe of variable delay. The triggering pulse may be connected either direct to the time-base circuit, or through a gated d.c. amplifier, or through a calibrated delay circuit to provide a strobed time-base.

The oscilloscope is supplied in two units, each approximately 24 × 12 × 18 in. The display unit weighs 55 lb and the power supply unit 100 lb. The latter, in addition to supplying the oscilloscope, provides two sources of voltage, one stabilized at +300 V and one at −300 V. A high current, unstabilized supply is also available at +480 V.

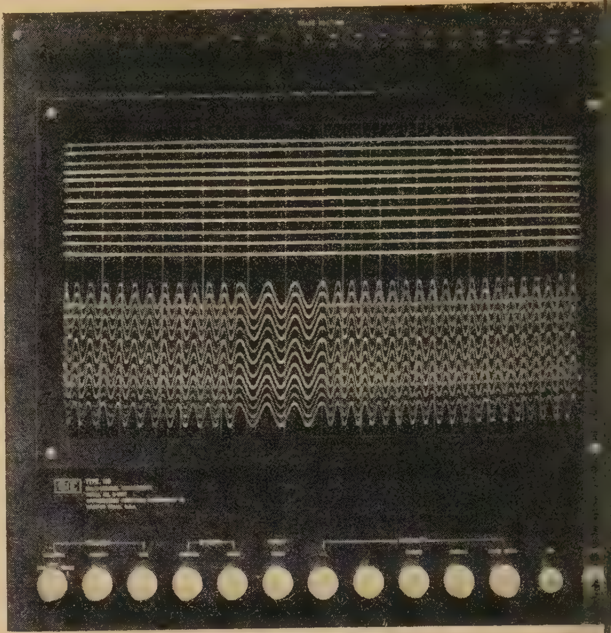
"White" noise generator. Dawe Instruments Ltd., 99 Uxbridge Road, London, W.5.

The type 419 "white" noise generator has been designed to produce electrical noise uniform in intensity over the entire audio and video frequency bands. Three bandwidth ranges are provided, covering 30 c/s to 20 kc/s, 30 c/s to 500 kc/s, and 30 c/s to 5 Mc/s respectively. The first of these bands covers adequately the whole audio frequency spectrum, and is intended for testing the acoustical properties of rooms, and the frequency response of audio amplifiers, loudspeakers and microphones. The 500 kc/s and 5 Mc/s bands can be used for filter tests and cross-talk investigations on multi-channel carrier telephony equipment. The energy levels on the three bandwidth ranges for 1 V r.m.s. output are 6 mV, 1 mV and 0·5 mV respectively when referred to an ideal 1 c/s band.

The noise source in the instrument is a thyratron placed in a transverse magnetic field. The magnetic field damps the oscillations which are usually produced by a gas discharge and largely equalizes the energy level of the noise spectrum. The spectrum is further modified by the two-stage wide-band amplifier which has three different filter networks between the first and second stages. In the 20 kc/s and 500 kc/s ranges, low-pass filters are switched in and these give a gradual cut-off for frequencies above the nominal band. In the 5 Mc/s range, the network is stated to compensate for the peak in the noise output of the thyratron at 700 kc/s, the fall in level at the higher frequencies producing a uniform noise spectrum up to 5 Mc/s.

Cathode-ray oscilloscope for twenty-four traces. Southwestern Industrial Electronics Co., 2831 Post Oak Road, Houston, Texas, U.S.A.

This cathode-ray oscilloscope uses a 21 in. television tube. The information is presented by intensity modulation of a 5000 c/s raster. The raster method results in a useful frequency response up to 500 c/s for all twenty-four traces. Each trace may cross over other traces, and is limited in amplitude only by the size of the cathode-ray tube. An auxiliary unit puts 0·1 and 0·01 s timing lines over the traces and triggers the sweep after an adjustable delay period following the initial pulse. A portion of the traces can be examined on an enlarged time-scale, as shown in the figure. The width and position of this portion of the traces is adjustable by a so-called "window control." One of the applications suggested for this oscilloscope is as a monitor for twenty-four-channel magnetic tape recordings use seismograph work.



Cathode-ray oscilloscope for twenty-four traces. auxiliary electronic circuit superposes the vertical tim marks. Note the enlarged time-scale for a portion the trace

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named.

Lens tissue and filter paper. J. Barcham Green Ltd., Hayle Mill, Maidstone, Kent. The range of papers made by this firm includes lens tissue and filter paper. A booklet entitled *Green's Lens Tissue Manual* describes the characteristics of the lens tissue and its uses. Another booklet with the title *Signposts* gives tables comparing the well-known makes of laboratory and commercial grades of filter paper. It also contains charts of ash content, speed, strength and weight of Green's filter papers.

Electronic instruments. The Solartron Electronic Group Ltd., Solartron Works, Thames Ditton, Surrey. The descriptions of instruments included in the latest catalogue are divided into the following sections: oscilloscopes; indicators; generators; converters; testers; computers; controllers; reproducers and power supplies. Headings included in anticipation of further data sheets are: servomechanisms; actuators and recorders. The catalogue also includes descriptions of imported instruments for which this firm is the sole U.K. agent.

Electronic measuring instruments. Marconi Instruments Ltd., St. Albans, Hertfordshire. The 1956 "electronic measurement" catalogue issued by this firm contains over one hundred items of equipment, of which about a quarter are claimed to be of new design. The sections into which the descriptions are divided are entitled: frequency measurement; voltage and power measurement; distortion measurement; transmission measurement; signal generators and accessories; oscillators and accessories; bridges and Q meters; television and radar test equipment; pH measurement; moisture measurement; industrial X-ray apparatus.

Electrical engineering data sheets. Johnson, Matthey Co. Ltd., 73–83 Hatton Garden, London, E.C.1. publication of a series of technical data sheets has been menced which will survey this company's products and ser for the electrical and allied industries. The sheets, which to be issued at the rate of two per month during the next or three years, will form Publication 1300 "Electrical engin ing data." The scope of the sheets is intended to be very the subjects covered ranging from circuit-breaker contac high-stability, silvered-mica capacitors. Some sheets make recommendations on the choice of materials, other design. Some will list the many standard products o company while others will contain information on asse methods.

The first sheets issued (dated April) are:

No. 1300: 300 Contact materials—properties and a ability.
No. 1300: 388 Contactors—choice of contact mate
No. 1300: 461 Silvered-mica capacitor plates.

Miniature electrical instruments. Measuring Instrum (Pullin) Ltd., Winchester Street, London, W.3. Catal Section A describes a range of miniature electrical in ments suitable for panel mounting.

Cast aluminium alloys. Alar Ltd., 3 Albemarle St London, W.1. The data sheets giving specifications trade names of cast aluminium alloys have been revise conform with the British Standard 1490: 1955.

Solenoid valves. Black Automatic Controls Ltd., Lea Corsham, Wilts. A set of data sheets gives full specifica of a range of solenoid valves.

Notes and comments

ions to The Institute of Physics

e following elections have been made by the Board of Institute of Physics:

llows: A. Abou-El-Azm, G. Black, R. J. Clayton, R. F. ing, A. E. Harper, J. C. Jones, G. E. Swindell, A. J. dall.

sociates: G. W. Alderton, H. L. Allsopp, L. W. Brown, 1. Burrows, I. Butterworth, T. Cartledge, C. D. Clark, . Copland, J. M. Dewey, R. G. Eades, A. S. Edmonson, . Fagan, D. Fishman, P. E. Francois, E. E. N. Gouw, Grove, Hon Yung-Sen, Ho Peng Yoke, D. P. Howlett, Hughes, A. J. Hymans, G. M. Jeffrey, T. G. Jones, . MacDonald, G. L. MacDonald, W. K. Mansfield, . Marr, G. H. Millard, G. B. Mummery, S. E. Orchard, . Rose, J. E. Samson, Panchanan Sen, Sunil Kumar Sen, haw, G. Slattery, W. R. Stamp, A. G. Stanley, G. R. or, D. P. C. Thackeray, Achyut Parashuram Thatte, . Ward, D. Wilkie, W. M. Williams, P. D. Wilmot, . Wolfendale, B. H. Woodcock.

rty-eight Graduates, twenty-eight Students and eleven cribers were also elected.

ications of The Institute of Physics

revised version of The Institute of Physics' list of ications is available. It includes brief details of the s published during the past few years in the Institute's ics in industry series and Monographs for students s. Details are also given of the Institute's two monthly nals and the supplements already issued. In addition, it ains information on the charts, nets and index cards h are available from the Institute for the use of X-ray allographers.

opies are available, without charge, from The Institute of ics, 47 Belgrave Square, London, S.W.1.

nal of The British Nuclear Energy Conference

e first issue of the *Journal of The British Nuclear Energy erence* has now been published. The Conference, as dy announced in these columns, is the permanent nization through which the Institutions of Civil, hanical, Electrical and Chemical Engineers and The tute of Physics collaborate in "advancing and dis-nating knowledge concerning the application of nuclear gy and ancillary subjects."

e Journal has an attractively designed cover carrying the s of the five constituent bodies of the Conference and has ages of text and 40 pages of advertisements. It contains ectures and papers presented at the opening Symposium in London on 30 November last and the discussion on contributions. They were: "The United Kingdom nic Energy Authority and its functions" by Sir John kcroft, "The place of nuclear energy in United Kingdom er development" by V. A. Pask and J. C. Duckworth, alth and safety in a nuclear power industry" by A. S. ean and W. G. Marley, and "The use of research reactors uclear power development" by H. J. Grout.

e subscription rate to this well produced Journal is .a. for non-members of the constituent bodies and 0*s.* p.a. for members of the constituent bodies. Orders subscriptions should be sent to the Secretary, The sh Nuclear Energy Conference, 1–7 Great George Street, don, S.W.1.

Nuclear Physics

We have received the first issue of a new monthly periodical entitled *Nuclear Physics*, edited by Professor L. Rosenfeld of the University of Manchester, and published by the North-Holland Publishing Company, Amsterdam.

One of the objects of this new venture is to provide for quick publication of original work "in such a form that it may be easily available to workers in the same field and come to their notice without the necessity of scanning huge piles of periodicals of the most varied description." In his editorial notice Professor Rosenfeld says "the new journal will be devoted to the experimental and theoretical study of atomic nuclei, not excluding those lines of research which may be expected to throw light on the nature of the nuclear forces, i.e. on the one hand the quantum theory of fields, on the other the investigation of the 'elementary' particles. This is, of course, no rigid delimitation of the scope of the journal; it may well become advisable to modify it from time to time.

"The emphasis will be laid on the publication of original papers, including extended reports of completed research as well as shorter notes announcing new results or presenting remarks and suggestions. An effort will be made to provide, whenever this may appear useful, longer review articles or shorter reports dealing with questions of topical interest. Moreover, as occasion arises, the journal will publish book reviews and news items of interest for nuclear physicists."

The issue before us measures $6\frac{3}{4} \times 9\frac{1}{2}$ in. and runs to 72 pages of text. The titles of the original papers are: Studies with the scintillation spectrometer; Interpretation of (d, t) angular distributions; Renormalization and mass levels; Formulation mathematique du modele de Gell-Mann; Observations of the energy spectrum of the cosmic radiation below ground; there is also a progress report entitled "New results on elementary particles at the Pisa Conference (12–18 June, 1955)" and a book review.

The subscription rate for the volume of 700 pages is 106*s.* and postage 8*s.* Orders should be sent to the publishers at P.O. Box 103, Amsterdam, or to any subscription agent.

Catalogue of nuclear reactors

We have received a *Catalogue of nuclear reactors* 1955 AECL No. 220 (CRR-590) prepared by Atomic Energy of Canada Ltd., Chalk River Project, with the co-operation of the Atomic Energy Research Establishment, Harwell, England. The following data is given so far as it is available: neutron speed (thermal, intermediate or fast), fuel configuration (heterogeneous, homogeneous), kind of moderator, purpose (research, plutonium production, propulsion, power), thermal power, neutron flux (at the speed implied by the first item above; maximum value unless otherwise noted). Construction details of each reactor are also given when this has been published. Copies of the catalogue can be obtained from H.M. Stationery Office, price 4*s.* 6*d.* net.

Conference on magnetism and magnetic materials

A conference on magnetism and magnetic materials will be held in Boston, U.S.A., on 16–18 October, 1956. It is sponsored by the American Institute of Electrical Engineers in co-operation with The American Physical Society, The American Institute of Mining and Metallurgical Engineers, and The Institute of Radio Engineers. Contributions are invited and authors should submit titles of proposed papers by 15 June and abstracts by 1 August, 1956. Further details may be obtained from T. O. Paine, Measurements Laboratory, General Electric Company, 40 Federal Street, West Lynn, Mass., U.S.A.

Glossary of terms relating to the performance of measuring instruments

A recent British Standard 2643: 1955 entitled *Glossary of terms relating to the performance of measuring instruments* should be of considerable help to manufacturers and users of instruments, some of whom, we regret to say, misuse many of the terms now defined. The instruments concerned are those designed to measure a range of values of some variable quantity, and as is remarked in the introductory notes, the difficulty of distinguishing between a gauge, a measuring instrument, and an apparatus is of little consequence for the present purpose. There are three sections to the glossary: design details; calibration and graduation; sensitivity and accuracy. The introductory notes include useful surveys of some of the many factors that have to be taken into account when considering errors in instruments. Copies of the standard can be obtained from the British Standards Institution, 2 Park Street, London, W.1, price 3*s.* net.

An international bibliography of mechanisms

Dr. P. Grodzinski has commenced publication of a monthly international bibliography on mechanisms. This is intended to index, classify and abstract the papers, articles and books on mechanisms which appear in the literature of all the most important industrial countries. In addition to purely mechanical devices (i.e. mechanisms in the strict sense of the word), electrical, electronic, hydraulic and pneumatic devices will also be included in this bibliography. This issue first contains brief references to about a hundred publications. Further details and particulars of the various subscription rates can be obtained from the publisher at 41 Tudor Close, Belsize Avenue, London, N.W.3.

Directory and handbook of British scientific instruments

The Scientific Instrument Manufacturers' Association of Great Britain Ltd. has just published its 1956 handbook. Its content is similar to previous editions but with the important addition of three language glossaries of the headings used in the index of products: French–English, German–English and Spanish–English. The format is "bigger and better" than previous issues, the index of products is more comprehensive, and the member firms' announcements are more informative. We congratulate all those who helped to produce this work and trust it will succeed in selling more British scientific instruments and components at home and abroad. There should be a copy in every laboratory and factory which uses instruments; copies may be obtained from SIMA House, 20 Queen Anne Street, London, W.1, price £1 2*s.* 6*d.* including postage.

Bibliography of information on servomechanisms and re subjects

The second addendum to the *Bibliography of inform on servomechanisms and related subjects* has now received. The bibliography was first issued in 1950 and prepared for the Interdepartmental technical committe servomechanisms (see *J. Sci. Instrum.*, **25**, pp. 224 and 1948). Limited supplies of the addenda and the bibliogr are available from the Ministry of Supply, TPA3/TIB Servo Library, 140 Leysdown Road, Mottingham, Lon S.E.9.

Report of a conference on engineering fastenings

Copies are available of the report of a conference he New York in April 1955 between America, Britain and Ca on the unification of engineering standards. Its purpose to smooth out some of the many small but highly impo differences which still exist between British and American practice in the design and manufacture of engi ing fastenings. The wide range of subjects discussed is shown by the following summary of the agenda, which constitutes the main headings in the contents list of published report: gauging of unified screw threads; un screw threads; unified bolts and nuts; acme threads; m scope objective threads; gas cylinder outlet threads; minology; surface finish; limits and fits; miniature bearings; informal discussion on the general subjec gauging.

The eighty-seven page report has been published on of the conference by the American Society of Mecha Engineers. Limited supplies are available at 10*s.* pe from the British Standards Institution, 2 Park Street, Lon W.1.

British Journal of Applied Physics

Contents of the April issue

SPECIAL ARTICLE

Physics of the Sun. By Z. Kopal.

ORIGINAL CONTRIBUTIONS

An apparatus for the accurate control of the peak X-ray energy of a 20 betatron. By K. Phillips.
Fields and stresses in dielectric media. By G. Power.
A new method for the measurement of rapid fluctuations of temperature R. Dehn.
The measurement of the electrical resistivity of silicon. By R. H. Creame
The Eberhard effect in X-ray powder photographs. By T. W. Baker.

NOTES AND NEWS

Correspondence

Ultra-violet polymerization of embedding monomers for thin sectioning. A. Charles and J. Sikorski.
Vapour lubrication of titanium and zirconium. From G. W. Rowe.
Observations on the characteristics of the cold cathode ionization gauge. J. H. Leck and A. Riddoch.

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principle construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Squar London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation contributions*. (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicati from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Londo E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 6 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addre or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable i advance. Single parts, so far as available, may be purchased at 10*s.* each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

A large optical slit mechanism employing spring movements

By Prof. R. V. Jones, C.B., C.B.E., F.Inst.P., Natural Philosophy Department, University of Aberdeen

[*Paper received* 2 *January*, 1956]

A spring layout is described for producing symmetrical movement in an optical slit 10 cm long, and capable of operating at any width between 5 and 1000 μ. Such factors as the parallelism and separation of the jaws are made independent of gravity by suitable arrangement of spring strength and disposition of centres of gravity of the moving members. The jaw edges are optically worked to confine width variations along the slit to about $\pm 0 \cdot 15\ \mu$ r.m.s., and the jaws can be set parallel by eye and hand to within about $0 \cdot 3\ \mu$ variation in the 10 cm length.

e large slits were recently designed and built in Aberdeen the twenty-metre solar spectrograph of the U.S.A.F. er Air Observatory at Sunspot, New Mexico. The useful th of the slit had to be 10 cm, the jaws had to be straight parallel within 1 μ over this length at all widths, and had to open symmetrically to a width of 1 mm. The would normally operate with its length horizontal, it also had to be capable of 360° rotation in a vertical e. The specified aperture ratio was only 1 : 100, but hat the design should be of more general application it made to transmit a much wider beam, of aperture ratio : 3.

ring designs were tried, based on those described in a ious paper,(1) to see how well these would perform in a comparatively large design. New problems thereby e, mainly because the straightness requirements in the entailed that these had to be made of comparatively and heavy material (6 mm stainless steel). The weights ich jaws and their carriers were not negligible compared the spring forces, as they had been in the design in the ious paper; and since the slit had to be capable of tion in a vertical plane the direction of gravity forces variable relative to that of the spring forces. The llelism and width of the slit had therefore to stay constant in 1 μ over 10 cm length, despite the changes in direction ravity relative to spring forces. The meeting of this last irement (which was laid down by the author, and not by observatory) might not in itself have been worth the t, since rotation of the slit will probably be an infrequent ation; but the meeting of such a stringent specification pure spring system should be a positive step in the design uch systems, and the experience gained may be of more ral application.

hree slits have been constructed. The first resembled in ciple that shown in Fig. 1 of the previous paper, except the reversing lever was mounted on a cross-strip hinge. as not fully tested regarding the rotation requirement, was sent to the Observatory for operation, where it tantially met the Observatory's specification. The con-ction of a second slit, which could be more rigorously d here, gave the chance of trying a simpler design. This nd slit completely met the specification, after minor ges, and enough experience was gained from it to justify ing a third slit to show that the design problem had been tered. This third slit met the specification immediately, the more important features of its design will be described his paper. Some of these features might usefully be ied to other types of spring mechanisms.

PRINCIPLES AND LAYOUT OF SPRING DESIGN

Fig. 1 shows the spring scheme. The jaw carriers C and C' are mounted each on two sets of parallel springs; C, for example, is carried on the spring pairs (1, 2) and (3, 4). The lever L, which generates equal and opposite motions in C and C' is mounted on an angle-spring hinge (9) of a type recently described.(2)

At this stage the statics of the system must be considered. Assuming that the pivoting point of the angle spring is on the line bisecting both jaw carriers, the pin P must lie to one side of this line and P' on the other. The spring pair (1, 2), for example, has then to take a bigger proportion of the thrust from P than does the pair (3, 4). If each pair is to undergo the same resultant deflexion (i.e. if the carrier C is to be translated parallel to its original direction) then springs (1) and (2) must be stronger than (3) and (4) in inverse ratio to their distance from the thrust line of P. Similarly springs (7) and (8) have to be stronger than (5) and (6). The strengths are best made correct by using the same thickness of spring material throughout, but making the stronger springs of greater width.

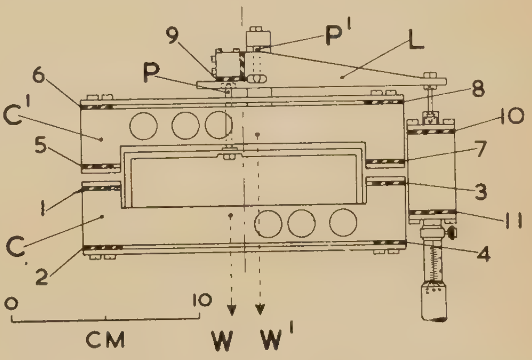


Fig. 1. Spring layout. (Springs shown shaded)

A further problem arises when the slit has to operate in all directions relative to that of gravity. If, for example, Fig. 1 is rotated through 180° in its own plane, the weight force on each jaw carrier will change direction by 180° relative to that of the pin thrust. This change of direction will tend to twist the jaw carrier unless the centre of gravity (of the jaw and carrier) is so positioned that the greater proportion of the weight acts on the stronger spring-pair. The centre of gravity has, in fact, to lie on the thrust line of the appropriate pin. This is best achieved by removing weight from the end of the jaw carrier nearer the weaker springs.

A consideration of the statics of the system when Fig. 1 is turned through 90° in either direction shows that for the weight forces to produce no twists in the springs in these positions the centre of gravity must lie half-way between the line joining springs (1) and (3) and that joining (2) and (4), assuming that, as is usually true for parallel-spring pairs, the components of each pair are of equal strength. Combining the statical considerations, we therefore conclude that the conditions for no twisting of the jaw carriers relative to the baseplate, as the system is rotated through 360° in a vertical plane, are:

(i) the "centre of strength" of the springs carrying each jaw should lie on the thrust line of the applied deflecting force, and

(ii) the centre of gravity of the jaw assembly should coincide with the "centre of strength" of the springs,

where the term "centre of strength" means that point in the plane containing the free ends of the springs through which the resultant of their reactions always acts, if the individual springs are deflected by equal amounts in any one direction.

The application of these conditions to the spring and weight layouts ensures that the jaws stay adequately parallel to one another. In the second slit as originally constructed, for example, proper attention was not paid to this point, in that the springs were all made of equal strength. The slit jaws thus lost their parallelism to the extent that if they were correctly set in one orientation, there would be 5 μ difference between the end widths in the 180° position. This represented a comparatively small angle, about 10″, which could be tolerated for some purposes; but with the springs of suitable strengths (and the centres of gravity accordingly adjusted) this loss of parallelism was made undetectably small, less than 0·5 μ over 10 cm.

A 180° rotation, however, may still cause a variation in width, as distinct from parallelism, of the slit. This is because the weight of the two jaws and their carriers is in part taken by the angle-spring hinge, and although this hinge is very strong, it may sag by a few microns in the extreme positions. If the end of the reversing lever remains fixed, the lever therefore changes direction slightly, causing the pins P and P' to move, and hence the slit to open or close by a few microns. This can be eliminated by mounting the driving micrometer on a parallel-spring pair (10) and (11), of such a strength that the micrometer moves a distance, owing to its own weight and that of the block holding it, equal to the sag on the angle spring. By a simple clamp of a type described in a previous paper,(3) the strengths of springs (10) and (11) can be adjusted to make the compensation apparently perfect. We thus have an all-spring mechanism capable of satisfying the specification.

DETAILS OF CONSTRUCTION

A rigid baseplate is essential; it is formed from a circular disk of mild steel 6 mm thick and 20 cm in diameter; the upper surface, as seen in Fig. 2, is scraped flat. The baseplate is further strengthened by a steel ring bolted to its lower surface; the ring also serves as the male part of a bearing which enables the slit to be rotated about its optical axis. The bearing, which is of conventional design, is fitted with a micrometer enabling the slit to be orientated to a precision of a few seconds.

A rectangular hole (12·5 × 3 cm) is cut in the base to let the light through. The jaw mounts are designed t disposed as conveniently as possible around this hole (Fi The jaw carriers C and C' and the corresponding bas and B' are shaped to give the maximum distance betwee members of each spring pair, for example S_1 and S_2. arrangement increases the length of the carriers, bu improves the geometry of the spring pairs, it increases resistance of the jaw-carrying assemblies to rotation, a enables the centre of gravity to lie very close to the centr strength.

The jaw carriers C and C' and the bases B and B' made from normalized mild steel 7 mm thick; they ar surface ground to the same thickness, which is about minimum that will stay flat to the limits required. Each carrying assembly is put together separately; the top sur of the slit jaws have to lie within 5 μ of the same plane, this is easiest achieved by having every component of the assembly identical in height with the corresponding me of the other. Identity of spring height between B an and B' and C', is ensured by inserting the same parallel-f rectangular block between B and C, and then between B' C', in the course of assembly.

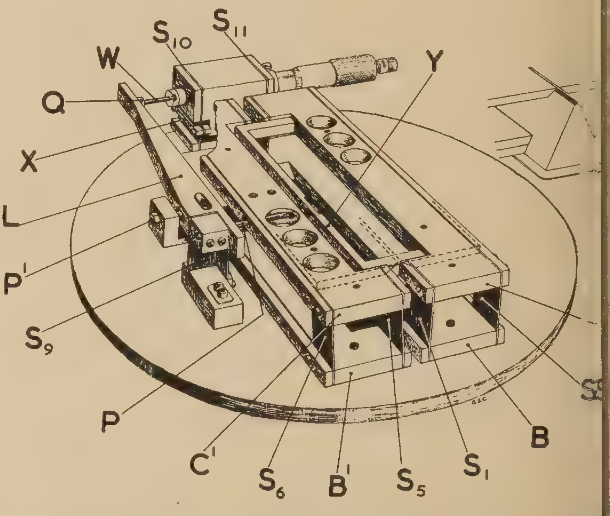


Fig. 2. Perspective view of assembled mechanis Spring numbers correspond with Fig. 1. *Inset*: Ro screen to be inserted through rectangular hole in ba

The reversing lever L is mounted on the angle sprin It pushes C through the pin P, which passes through a in C' and is attached to the yoke Y which is fastened t The yoke is somewhat thinner than the carriers C and that it does not rub against the jaw carried on C'; its di sions are such that, while it is sufficiently strong, it doe obscure the light path or foul other components. The L pulls on carrier C' by pushing against the pin P' wh carried on an angle bracket fastened to the underside o

Apart from the simplicity of its construction, the spring allows the pins P and P' to lie nearer the ax rotation than could easily be done with a normal piv comparable strength. The designed distance is 5 mm, w with a driving arm of 10 cm gives a reduction of 10 : the slit width compared with the micrometer move The setting-up procedure is as follows: first the dist between P and P' is set as nearly as possible to 10 Then the angle spring is set for equality of motion bet jaws, adjustment being effected by small movements of angle-spring base in the direction of the length of the r. Then the reduction ratio is made as nearly exactly 1 as required by moving the female cone Q (receiving wobble-pin W) along the lever arm. It is fixed in a ed hole for this purpose. The wobble-pin is of the d type recently described.(4)

o test the behaviour of the system the jaws are attached, being fixed to its carrier by two screws. When the jaws separated by two microns or so, and illuminated by light behind, it is easy to see any departure from parallelism hange in width as the mechanism is rotated in a vertical e. Departures from parallelism can be cured by adding ht on one side or other of one or both of the jaw carriers, if the springs have been correctly cut, little balancing ld be necessary. Changes in width are due to springs and S_{11} being of incorrect strength. A few trials should lt in these springs being approximately correct; it is enient to make them slightly weaker than the correct gth, and then to strengthen one (or both) of them by amp shown as X in Fig. 2; this gives a fine adjustment, ng minimum effect at the middle of the spring, and a imum near the ends.

o minimize temperature effects in distorting the system, made of mild steel throughout, except for the jaws, h are of stainless steel, and the springs which are of llium copper in the condition known commercially as f-hard."

he mechanism has to be made light-tight. This has been t easily done by making a roof-shaped screen of thin s, which is inserted from underneath through the angular hole in the baseplate. The apex of the "roof" open slot, of width greater than the maximum opening ired in the slit. This slot is placed well up into the oove formed by the 45° faces on the slit jaws. If the en is correctly placed light should be satisfactorily uded; the screen should be dull-black. The highest ible aperture is obtained by undercutting the baseplate the individual bases B and B' (Fig. 2). Further screening be provided if necessary by adding small stops in the oove formed by the 45° faces just beyond the extremities e roof screen.

n adjustable diaphragm is added so that the effective th of the slit can be limited as desired. This is of the entional pattern, and is carried on one of the jaws; it is shown in the figures.

eally the sides of the slit should be as near knife-edges possible. The making, mounting, and preservation erfect edges are, however, three independently difficult ations which together become virtually impossible. A promise profile is therefore adopted along the lines of 3(*a*), where the edges are blunted to flats 30–50 μ wide. exact figure depends on the length of jaw to be made mounted, and on the material used. It is better to nt the jaws so that the top surface in Fig. 3(*a*) faces the source, since the jaws then form a flat surface right up e slit edges: this is convenient for seeing that the source aged in the slit. It may be desirable to polish this ce, to ensure minimum absorption of radiation from the ce.

different jaw profile, which may sometimes be useful, is n in Fig. 3(*b*), where the slit walls are very much deeper. ey were perfectly reflecting, all the light falling on the end of the slit would emerge from the narrow end. would enable a wide-aperture spectrograph to be filled light from a narrow-aperture pre-slit system. The arrangement amounts to combining cone-optics with a conventional slit. It has been tested, and works quite usefully, subject to the limitation that the light emerging from the slit at large angles to the original direction is heavily polarized by its repeated reflexions at the slit walls.

The jaws are made of stainless steel (Firth Brown type S 80). The material has been used both in the hard and soft states, and rather better results have been obtained with the latter. The jaws are first milled roughly to shape and softened. Their upper and lower surfaces are then ground flat and parallel, care being required to ensure that the jaws are of equal thickness within a few microns. It is easy to induce distortion by the use of a magnetic chuck and by surface work-hardening in the grinding; care must therefore be taken to check the jaws for thickness and flatness before proceeding to grind the 45° faces. This last grinding operation should take the jaws to as near knife-edges as possible.

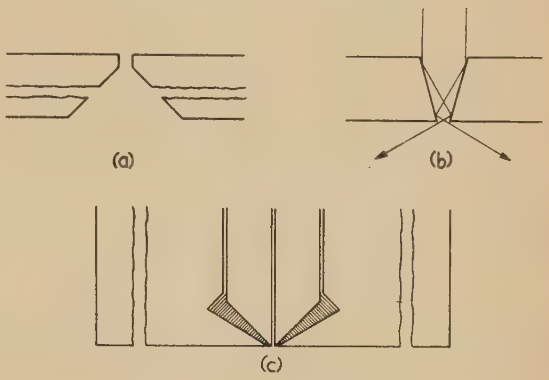


Fig. 3. (*a*) Normal jaw profile. The 45° knife-edges are blunted to 50 μ flats. (*b*) Alternative profile, not to same scale as (*a*), where jaw edges are angled to give a "light-funnel," to increase light flux through the slit. (*c*) Steel-shellac "sandwich" for working the small flats of profile (*a*). Shellac shown shaded. The composite under-surface is subsequently lapped and polished

The edges have then to be blunted to 50 μ flats, the flat on each jaw being at right angles to the upper surface of the jaw [Fig. 3(*a*)]. The two jaws with their sharply-ground edges are placed back to back with these sharp edges contiguous, and embedded in a hard wax or shellac sandwich between other suitably-shaped pieces of steel of the same overall length as the jaws and 1 to 2 cm thick [Fig. 3(*c*)]. The composite surface is then ground and polished by ordinary optical working; in this process the sharp edges are worked away to flats of the desired breadth. After this the jaws are extracted, and placed edge to edge. Generally, they will be found then to touch at various points along their length; at others they may be a micron or so apart. The "high spots" are marked, and removed, one-half from each jaw, by rubbing with a flat piece of ebonite or plastic-impregnated wood charged with chromic oxide polishing powder. By repetition of this process, the jaws can be made sufficiently straight and parallel to obscure light along their entire length. The best results have been achieved with a final working with a diamond-dust lapping compound. Examination with an interferometer microscope showed that the small flats could be worked to within about two fringes of the intended flat profile.

PERFORMANCE

Mechanism. The mechanism behaved satisfactorily, as the following figures show:

parallelism of jaw opening: each jaw within 3″ of the other, and of its own original direction, up to 1 mm slit width;

symmetry of jaw opening: worst drift of centre line 1·5 μ, from zero up to 1 mm slit width;

accuracy of width indication from micrometer reading: better than 0·7%;

variation of parallelism as slit rotated through 360°: less than 0·5 μ along 10 cm length;

variation of width for given micrometer setting, as slit rotated through 360°: less than 0·5 μ.

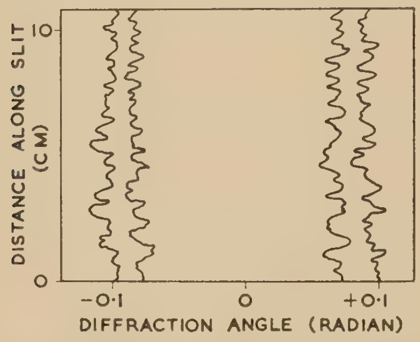


Fig. 4. First diffraction minima at ±0·085 rad on either side of central maximum: slit width 6·4 μ. Each minimum is delineated by a pair of lines traced from a density contour in the photographed pattern. Irregularities in the contour are caused by variations in width of slit and in depths of slit walls

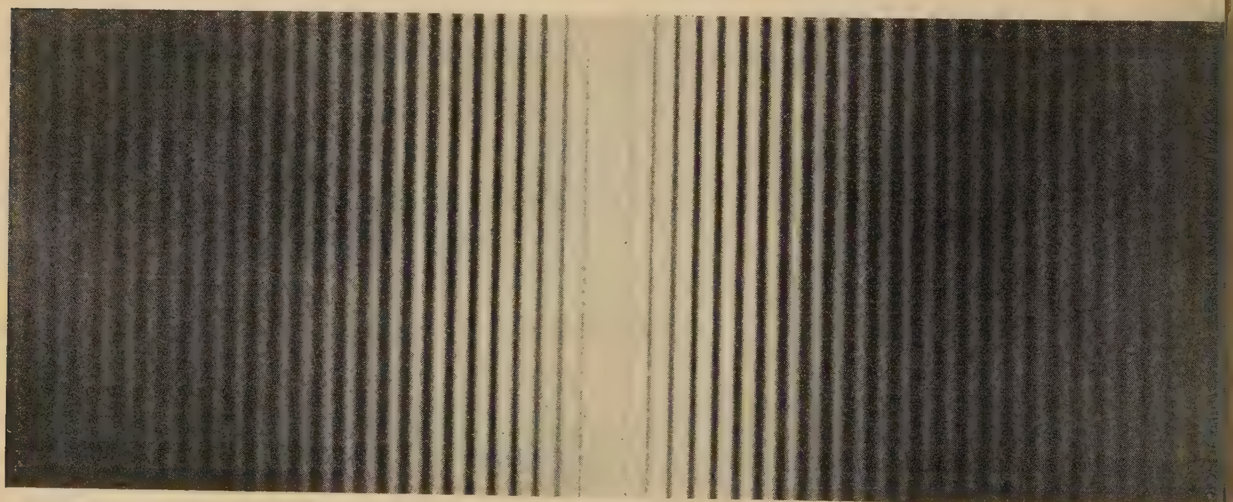


Fig. 5. Fraunhofer diffraction pattern from slit at 110 μ width, for 5461 Å light

Jaws. The performance of the jaws is best shown by diffraction records, Figs. 4 and 5. Fig. 4 is a tracing from a photograph showing a density contour around the first minima on either side of the central maximum in the Fraunhofer pattern from a pair of jaws at 6·4 μ width, using a point source to show up the irregularities as sharply as possible. Irregularities in width affect the distance between the minima, while irregularities in depth affect the inte thus giving rise to a complex density contour. Judge the distance between the minima, the variations in the of the slit along its length had an r.m.s. value of about 0· the jaws had been set parallel to within about 0·3 μ in 10 cm length (this could be done quite easily by eye hand).

Fig. 5 shows the pattern for another pair of jaws whe slit is about 110 μ wide. This pair is about as good a pair used for Fig. 4; in fact, several pairs were made w comparable performance. From the point of view of ducing satisfactory diffraction pictures of the remoter ma the slit has not only to be of constant width, but al uniform depth along its entire length. The amount of falling in the maxima at an angle of more than a few de to the direction of the main maximum is very depen upon the uniformity in depth of the slit edges. This is a immaterial in the use of the slit for spectroscopy, when central maximum only is concerned, but it is rather tr some to produce jaws good enough to give uniform diffraction pictures of the quality of Fig. 5. Fig. 5 shows, incidentally, that the slit will pass light satisfac up to an aperture ratio of 1 : 3.

LIMITATIONS

The first slit has been operating satisfactorily in Mexico for eighteen months, but no evidence is yet ava regarding the ability of the mechanism to hold the formance given in the preceding section, which was ach on initial adjustment without undue difficulty, and was beyond the specification. Such factors as cha flatness of components through aging might distur adjustment, despite care being taken to relieve in stresses by annealing.

Further, the slit, when very narrow, introduces pol tion(5) of a magnitude which may be serious in applications (e.g. Zeeman effect studies). The effect, is due to the finite depth of the slit, and to the imp conductivity of the jaws, might be reduced by makin jaws sharper, but in this respect the present design is its practical limits. If freedom from polarization is nec it might be better to resort to a virtual slit of the “kr

le" type sometimes used in the past and recently shown
Icllwraith(6) to be worthy of serious development.

ACKNOWLEDGEMENTS

ne first of the three slits was largely designed by Dr.
I. S. Holbourn while the author was on leave of absence
the Ministry of Defence. The construction of all three
owed much to the patience of Mr. C. J. Meldrum and
G. Watson.

REFERENCES

(1) Jones, R. V. *J. Sci. Instrum.*, **29**, p. 345 (1952).
(2) Jones, R. V. *J. Sci. Instrum.*, **32**, p. 336 (1955).
(3) Jones, R. V. *J. Sci. Instrum.*, **28**, p. 38 (1951).
(4) Jones, R. V. *J. Sci. Instrum.* To be published.
(5) Jones, R. V., and Richards, J. C. S. *Proc. Roy. Soc. A*, **225**, p. 122 (1954).
(6) McIlwraith, A. H. *Proc. Phys. Soc.* [*London*] *B*, **429**, p. 649 (1955).

A remotely-controlled traversing yawmeter for boundary-layer exploration

By D. W. Bryer, A.F.R.Ae.S., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 9 *December*, 1955]

The report describes a remotely-controlled yawmeter traversing apparatus which has been constructed at the National Physical Laboratory. A high degree of accuracy, 0·001 in. in traverse and 0·05° in rotation, together with rapid operation and direct indication of position, is achieved by mounting the yawmeter on a micrometer mechanism which is controlled through flexible drives by reversible motors incorporating revolution counters. Details are given of the design, which includes safety devices and a system whereby the traverse is related to an accurate datum position.

estigations of three-dimensional boundary layers have
wn that measurements of velocity, total head and flow
ction are best observed at the same time with a single
sure-probing instrument. This is particularly desirable
swept-wing research because of the rapid change in flow
ction frequently encountered near the wing surface.
oner(1) has described a technique for boundary-layer
oration with a Conrad yawmeter consisting of two tubes
ened side-by-side with their forward ends chamfered to a
nt. This method has been further examined at this
ratory.(2) Velocity is determined from the pressure
erence in the two tubes after the probe has been rotated
ugh 10° from the "into wind" position; this pressure
erence is linear with angular displacement of the probe,
ch must therefore be known within 0·05° to obtain an
racy of 0·5% on dynamic pressure. In determining the
lacement thickness of thin boundary layers, it is also
essary to know the distance of the probe from the wing
ace within 0·001 in., so that the technique demands an
rate method of finding a datum position. Furthermore,
probe and its carrying mechanism must be as small as
ible to reduce interference in the wind stream.

he paper describes a pressure probing apparatus which
ls the requirements mentioned above. To facilitate wind
nel tests, it is desirable to control movements of the probe
n outside the tunnel, and two flexible drives are used for
purpose. Mechanical transmission and conversion of
motion is adopted in order to eliminate the uncertainty
peration which frequently occurs with electrical systems
g contacts or impulse devices subject to dirt and wear.
motion in the flexible drives is minimized by incorporat-
all the gear reduction in the micrometer head; one
lution of one flexible drive gives 0·001 in. traverse and
revolution of the other drive represents 0·1° rotation,
e being recorded by counters in a control unit. The
slational and rotational movements are independent of each other, and the design includes limiting and safety devices to prevent damage to the instrument and model. The apparatus was designed in the Aerodynamics Division, and the micrometer mechanism was constructed in the Metrology Division of the N.P.L. The principal features, illustrated in Fig. 1, are as follows:

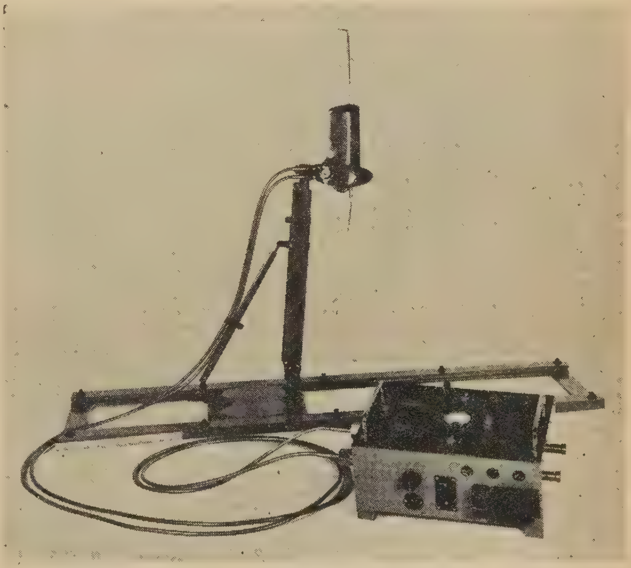


Fig. 1. Remotely-controlled traversing yawmeter

(*a*) A micrometer head carrying the probe and accurate to 0·001 in. in traverse and 0·05° in rotation. The length of traverse is 3·75 in. and the probe may be rotated through an angle of 280°.

(*b*) An adjustable stand mounted on rails and carrying the micrometer head.

(*c*) A motor-driven control and position-indicating unit connected to the micrometer head by two flexible drives each 12 ft long.

(*d*) A meter on the control panel to indicate contact between the probe and wing surface.

DETAILS OF APPARATUS

Micrometer head. A diagram of the micrometer mechanism is given in Fig. 2. The probe is carried by a hollow shaft running in a plain bearing at its upper end whilst the lower end, which is of larger diameter and carries a vertical spline, runs in a worm-wheel hub containing a keyway, the worm-wheel forming the second in a double worm-gear train giving a reduction of 3600 : 1 from the lower flexible drive connexion. Backlash in the rotary drive is overcome by fitting a disk with keyway above the second worm-wheel hub and connecting the disk to the earth frame with a coil spring; the disk is held by set-screws to the worm-wheel hub but is allowed a small degree of freedom in rotation relative to it. The vertical traverse is determined by a nut travelling on a lead-screw of twenty threads per inch and driven by a worm and worm-wheel giving a reduction of 50 : 1 from the upper flexible drive connexion. A fork projecting from the nut and having its ends lightly sprung between two flanges on the hollow shaft, transmits the motion, whilst the nut is prevented from rocking by two adjustable bars attached to it and slid on the earth frame; a tongue engages a slot in the earth fra to prevent rotation of the nut and a second smaller nut a similar tongue is located above the first and forced a from it by a short coil spring to remove backlash. A l spring bearing on the upper end of the lead-screw preve end-play by forcing it against a ball bearing at its lower e Electrical contacts, attached to the earth frame and insula from it, are earthed when the lead-screw nut reaches eit limit of its traverse, so completing a circuit which stops traverse motor: the rotary drive is limited by removin number of teeth from the second worm-wheel and provid a stop.

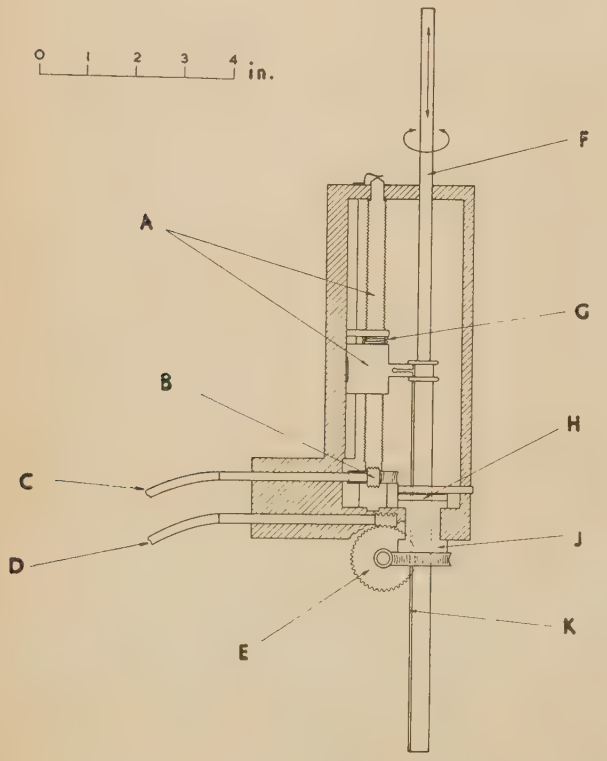


Fig. 2. Diagram of micrometer mechanism

A, lead-screw and nut; *B*, worm and worm-wheel; *C*, traverse drive; *D*, rotary drive; *E*, double worm and worm-wheel; *F*, tube carrying yawmeter probe and connexions; *G*, coil spring; *H*, disk with keyway; *J*, worm-wheel with keyway; *K*, spline.

Adjustable stand. The stand carrying the micrometer h is designed to be fully adjustable. The head is bolted t universal joint which forms the upper end of an extensi streamlined shaft, the lower end of which has another univer joint attached to a turntable; fore and aft stiffness of the sh is increased by the addition of a bracing strut fastened sliding clip to the shaft and by a ball joint to the turnta The whole of this assembly is mounted on a carriage sli in grooves between two rails, one of which is marked al its length to give adjustment of the carriage position within 0·01 in. All adjustable parts of the stand ma clamped rigidly. Unevenness of the tunnel floor is overco by arranging for the fastening screws to pass through centres of adjustable feet spaced at intervals along rails.

Control and position indicators. The control and posi indicating unit consists of a box containing the two dr motors, counter mechanism and electrical system. Fig and 3 show views of the outside and inside of the unit resp tively, whilst Fig. 4 is a diagram of the electrical circ The traverse drive motor and rotary drive motor are pla

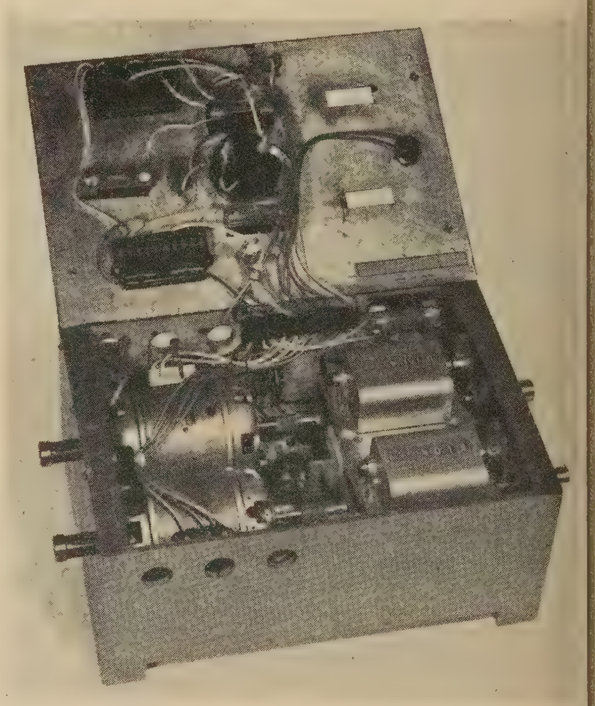
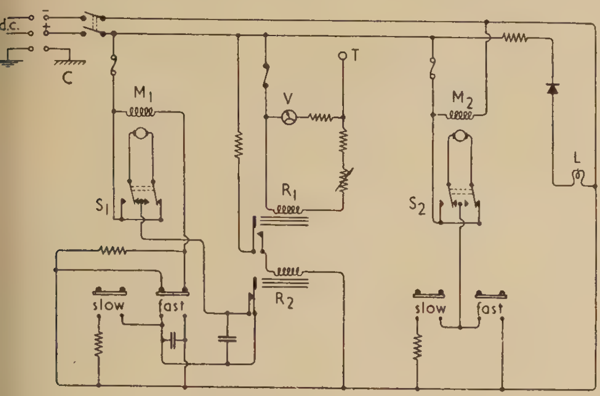


Fig. 3. Control and position-indicating unit wit control panel lifted

-by-side, each being connected by rubber sleeves to rate shafts which extend to the flexible drive connexions ie outer end of the box. Spur gears on each shaft form drive to a revolution counter mounted under the control el; the last figure of each counter is "direct drive," and cates 0·001 in. for traverse and 0·1° for rotation. The or shafts are extended through the end of the box opposite flexible drive connexions and carry small thumb-knobs provide fine adjustment by hand in addition to the slow fast push-buttons and reversing switches mounted on control panel. The traverse motor turns at 2000 rev/min fast and at 800 rev/min on slow: the rotary drive motor ns at 1600 rev/min on fast and at 700 rev/min on slow. 110 V d.c. supply is led in through a three-pin polarized g at the front of the box to a two-pole one-way switch t to it, the motor circuits being protected by external s. An indicator-lamp lights when the main switch is on the polarity of the supply is correct, but if incorrect arity occurs, a small metal rectifier in circuit with the p will not pass sufficient current to light the bulb.



ig. 4. Circuit of control and position-indicating unit

, chassis; *L*, indicator lamp; *M*$_1$, traverse motor; *M*$_2$, yawing otor; *R*$_1$, fast relay, 2 mA; *R*$_2$, fast relay; *S*$_1$, *S*$_2$, reversing switches; *T*, terminal; *V*, millivoltmeter.

robe contact indicator. A millivoltmeter situated in the tre of the control panel is used to indicate contact between probe and model surface. With wooden models, the ace is first coated with graphite paint which must then rubbed down with fine abrasive cloth to produce a conting layer. At the rear of the control panel is a terminal which the conducting surface of the wing is wired, the ninal being connected through a high value resistor to side of the millivoltmeter, the other side being connected ough a single-pole switch to the positive supply so that indicator circuit is completed when the conducting wingace is earthed by the tip of the probe. When the indicator uit is closed, a sensitive relay system is brought into ration, whereby the supply to the armature of the traverse or is cut off as a safety measure: by wiring the contacts he micrometer head to the terminal on the control el, the same system serves as the traverse limit switch. relay system will work on a current of only 2 mA, but he conducting surface has a resistance greater than 00 Ω, a variable resistor, placed at the front of the , is reduced until the relays will operate. The high tance of the circuit obviates the need for a good ace contact, whilst the low current prevents overheating ie probe tip.

NOTE ON CONSTRUCTION

In general, the instrument was made to ordinary workshop standards, but parts of the micrometer mechanism required more careful machining. Special care was necessary when making the hollow shaft which carries the probe, where a small misalinement of the spline or horizontal flanges would result in interference between the two motions. To avoid this, the shaft was assembled before finishing to size. The side of the spline was ground by traversing the shaft through two bearings spaced at the same distance apart as in the final assembly; a "finger" attached to the shaft with its end bearing on a length of gauge-bar held parallel to the axis of the bearings, prevented the shaft from turning, and an oversize keyway was cut in one bearing to clear the spline. An alternative would be to adopt a square section for the lower end of the hollow shaft, which would simplify the machining operations. The worms were ground from hardened steel and the worm-wheels made of phosphor-bronze; these materials are essential for the final reduction on the rotary drive where uneven distribution of wear is likely to occur. The torsional stiffness of the inner flexible-drive shafts should be as great as possible; six-core shafts of $\frac{3}{16}$ in. diameter were found satisfactory.

CONCLUSIONS

The apparatus, designed as general wind-tunnel equipment, has remained serviceable after considerable use. Similar apparatus based on the N.P.L. design has been built at other establishments.

Examination of the Conrad yawmeter technique has shown that, for measurements of velocity in the attached three-dimensional boundary layer, an overall accuracy of ±1·6% is attainable,(2) when the angle of pitch of the yawmeter remains within ±6° of the local mean-flow direction. Several other types of pressure probe have been operated with the apparatus.(2)

In regions of detached flow, such as occur in the wake of a wing at high incidence, measurements of velocity and flow direction are best obtained with an instrument which can be alined to the local mean-flow direction. For this purpose, further apparatus incorporating in addition the remote adjustment of pitch is being developed at the N.P.L.

ACKNOWLEDGEMENTS

The work described above was carried out in the Aerodynamics Division of the National Physical Laboratory, and it is published on the recommendation of the Aeronautical Research Council and by permission of the Director of the Laboratory.

Acknowledgements are due to Mr. E. P. Goymour of the Metrology Division, who built the micrometer head, and to Mr. N. G. Marcus of the Aerodynamics Division, who prepared detailed drawings of many of the mechanical parts.

REFERENCES

(1) BREBNER, G. G. *Pressure and boundary-layer measurements on a 59° sweptback wing at low speed and comparison with high-speed results on a 45° swept wing.* Part I (February 1949). Part II (August 1950). C.P.86. (A.R.C.)

(2) BRYER, D. W., WALSHE, D. E., and GARNER, H. C. *Pressure Probes Selected for Mean-flow Measurement. Exploration of Turbulent Boundary Layers.* A.R.C. 17,997 (November 1955).

Two designs for a paramagnetic oxygen meter

By A. Hobson, M.Sc., A.M.I.E.E., A.Inst.P.,* Admiralty Research Laboratory, Teddington, Middlesex, and
R. H. Kay, M.A., D.Phil., A.Inst.P., The University Laboratory of Physiology, Oxford

[*Paper received* 5 *January*, 1956]

A robust oxygen detector capable of giving direct readings on a meter or recorder has many applications in physiology or in the control of chemical processes. Physical methods at present available commercially have characteristics which often make them unsuitable for particular applications. This paper describes two separate but parallel investigations of the design of an oxygen meter depending on the paramagnetism of oxygen and the change of its susceptibility with temperature. One instrument covers 0–100% oxygen concentrations at or near atmospheric pressure, the other 90–170 mm of mercury partial pressure of oxygen in total ambient pressures of about 600–900 mm of mercury.

1. INTRODUCTION

A compact robust oxygen detector, capable of giving direct readings on a meter or of being coupled to a continuous recorder, has many applications in physiology and in the control of chemical processes.

Intermittent gas sampling and subsequent chemical analysis soon become unwieldy when the concentration of oxygen in the gas mixture is varying greatly. Such tests fail to give a continuous record of changing conditions and, in general, the techniques involved are too complex for routine work, e.g. in a hospital.

Other physical methods at present available commercially have characteristics which often make them unsuitable for particular applications. Thus, in the measurement of thermal conductivity (1–9) the effects due to oxygen are often masked by variations in the concentrations of other gases, while in the Beckmann–Pauling paramagnetic oxygen meter,(10) the fragility of the very thin fibre suspension of the test body prevents measurements being made under conditions of vibration or shock.

An overwhelming advantage of the paramagnetic method is that it is specific to oxygen alone, in any gas mixture likely to be inspired (see table), whereas the thermal conductivity method is by an order of magnitude more sensitive to changes in, for example, carbon dioxide or water vapour concentration than to oxygen changes, necessitating complete removal of those gases before analysis.

This paper describes two separate investigations of the design of an instrument depending on the paramagnetism of oxygen and the change of its susceptibility with temperature. Both developments arose from the apparatus described by Naumann(11) and the use of indirectly heated thermocouples which had previously been found to be extremely robust and constant in performance when used in katharometers.(12)

One instrument was designed to cover 0–100% oxygen concentrations at or near atmospheric pressure, while the other was an experimental approach to an instrument measuring 90–170 mm of mercury partial pressure of oxygen in total ambient pressures of about 600–900 mm of mercury.

2. METHOD

The method involves a comparison of the cooling of two similar heated wires enclosed in two thermally identical chambers. In one chamber the hot wire is situated in a high and non-uniform magnetic field, and in the other chamber in a field-free space. The latter wire comes into thermal equilibrium with the convection current it drives, the for
with this normal convection current enhanced by the pres
of oxygen in the magnetic field gradient.

Much variation is possible in the detailed geometr
oxygen meters of this type,(13–15) but, if we represent
chambers (*a*, *b*) and hot wire elements (W_1, W_2) schemati
as in Fig. 1, then the cooling of the wire depends on:

(i) the normal convection current produced by the
wire. This remains largely independent of ox
content of the gas in chamber (*b*);

(ii) the enhanced convection in chamber (*a*) due to mag
forces on the oxygen molecules. Cool oxygen a
say, is attracted to the region of high magnetic fie
which the wire is situated. It is there heated an
susceptibility falls according to Curie's law.
results in a net magnetic force acting to displac
oxygen of low volume susceptibility at W_1 by co
oxygen of higher susceptibility from regions such
This net magnetic force is in the same sense as th
gravitational force on the convecting gas in the
uniform temperature field. It enhances the gas
past the heated wire, cooling W_1 more than W_2.
gas heated at the wire rapidly cools to ambient tem
ture on contact with the walls of the chamber an
cycle is repeated.

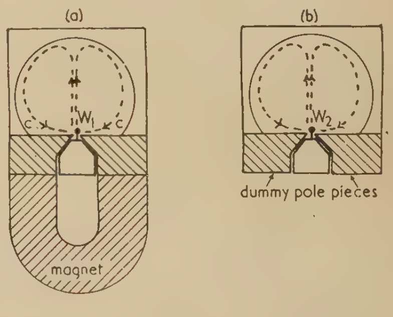


Fig. 1. The gas chambers

(*a*) Magnet chamber. (*b*) Comparison chamber.

The net magnetic force F, near W_1, attracting cold vo
elements of oxygen (absolute temperature T_1) preferen
to heated elements (T_2) may be written:

$$F \propto H \frac{dH}{dx}\left(\frac{p}{T_1^2} - \frac{p}{T_2^2}\right)$$

where H is the field and dH/dX the field gradient nea
the final bracketed term accounts for the variation i

---

* Now at Department of Physical Research, Admiralty, London. Member of the R.N.S.S.

ıber of oxygen molecules present per unit volume as a ction of partial pressure (p) and absolute temperature (a term p/T), and also for the temperature dependence of ceptibility according to Curie's law (a term $1/T$).

'or sensitivity, then, the wire must be sited in a high field l in a high field gradient. Its temperature must be reciably higher than the ambient gas temperature. For atest sensitivity there must also be efficient heat transfer ween the wire and the gas, both to keep the magnetic ct high and also to ensure maximum differential cooling he wire by the enhanced convection.

Vhen a large range of oxygen concentration is to be asured, some of the sensitivity achievable at low con- trations must be sacrificed in order to obtain adequate sitivity at the higher end of the range. If this were not ne, the greatly enhanced convection velocity at the higher centrations would become too large for adequate heat nsfer between the gas and the measuring wire. A com- mise is arranged so that the calibration remains reasonably ear throughout, either by moving the wire to a region of ver field and/or field gradient or by reducing the wire nperature. The final adjustment is largely empirical ause of the multiplicity of factors affecting the cooling of wire. The steady state wire temperature for zero oxygen pends on some function of gas density and gas thermal iductivity of the magnetically inert gas. If these are low s equilibrium temperature of the wire will be higher and sitivity to the paramagnetic effect increased [equation (1)] l *vice versa.*

3. CONSTRUCTION AND ADJUSTMENT

3rief separate descriptions of the Admiralty Research ɔoratory (ARL) and Oxford models follow; thereafter y will only be referred to separately when tests specific to model are described.

ARL model.

Two hemispherical brass cavities, 1 in. diameter, are cut each of two brass strips and these are mounted together h conical intrusions into the cavities in one plate to give assembly shown to scale in Fig. 2. One conical intrusion sists of two steel pole pieces mounted in brass with a mocouple protruding through the two poles; the other ical intrusion is geometrically similar but has dummy pieces of brass.

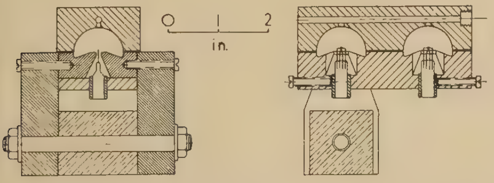


Fig. 2. Paramagnetic analysis cells (A.R.L. model)

he thermocouples are connected in series opposition in uit with a galvanometer (100 Ω coil, 15 cm deflexion per . The supply to one of the heaters is fixed at 90 mA that to the other includes a series variable resistor so with nitrogen in the unit the heater current can be isted for zero galvanometer deflexion. The volume of cavity is about 5 cm^3. The gas enters by breather holes ween the cavities and a horizontal gas duct, through which sample flows at 50–500 cm^3/min.

To avoid variations due to temperature fluctuation, the equipment is mounted in a small thermostatically controlled box. Pressure variation of the calibration is eliminated by a pressure transducer (section 4.5). A small volume cavity was shown to be best on two counts, first that the response time was reduced and second that the convective cooling of the wire was more efficient.

(*b*) *Oxford model* (Fig. 3).

The chambers are bored out of Duralumin bar, sealed with Duralumin end pieces, rigidly bolted to a thick Duralumin plate and cemented gas-tight with hot setting Araldite 1. The tapered magnet pole pieces are mild steel with brass inserts to complete the seal at the base of the chamber; the dummy pole pieces are geometrically identical but made of brass throughout. The magnets are type M129 by Mullard Ltd.

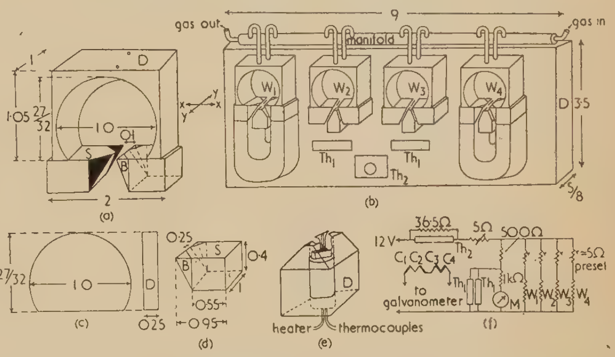


Fig. 3. Oxygen meter assembly (Oxford model). All dimensions given in inches

S, mild steel; *B*, brass; *D*, Duralumin.

(*a*) One chamber.

(*b*) Assembly of the four chambers.
Th_1 = thermistor type F 2311/300.
Th_2 = thermistor type KB 2231/80.
W_1–W_4 = heaters.

(*c*) Plugs (fitting flush into each end of the chamber).

(*d*) Pole pieces.

(*e*) Heater-thermocouple in mount.

(*f*) Circuit diagram.
C_1–C_4 = thermocouples.
$W_1 W_4$ = heaters.
Th_1 = thermistor type F 2311/300.
Th_2 = thermistor type KB 2231/80.
M = meter, 1 mA full-scale deflexion, internal resistance 40 Ω.

The sampling gas must flow into the chambers sufficiently slowly so that the convection currents are undisturbed; the volume of each chamber is, however, only about 5 cm^3 and, by a suitable adjustment of the manifold feeding in the gas sample, a main tube sampling velocity of only 100 cm^3/min can give a response time to 90% full-scale deflexion in twenty seconds. Dead space in the sampling system can increase this figure. The instrument will work well with two chambers only, but four provide sufficient variables better to eliminate differences between individual heater-thermocouples. Linearity and useful range are also more easily controlled.

The wires are run at about 300° C above ambient temperature; the enhanced convection in the magnetic chambers on full oxygen reduces the wire temperature there by about 60° C. The thermocouples in each pair of chambers are connected in opposition and the two opposed pairs additively. The position and temperature of the wires is arranged to satisfy two conditions: first that with the magnets removed from their pole pieces the output is zero for any gas composition the instrument is likely to encounter in use. The differential output of the thermocouples with the magnets replaced then becomes a measure of the magnetic properties of the gas mixture sampled; and second that adequate sensitivity is available over the whole operating range.

In both models the heater-thermocouples are specially made by Ormandy and Stollery, Brightlingsea, Essex. The heaters are 4·5 mm lengths of 25 μ Nichrome 80/20 and have cemented to them three chromel P copper-nickel couples to monitor the wire temperatures. The heater resistance is 10 Ω nominal ±10%, the rated heater current 100 mA, the triple couple resistance 20 Ω nominal and the couple output at 100 mA heater current in air is 40–50 mV.

4. PERFORMANCE

4.1 *Range, linearity and accuracy.*

(*a*) *The ARL model.* This model was adjusted to cover the range 0–25% oxygen (at atmospheric pressure) and calibration tests at atmospheric pressure made by varying the percentage of oxygen in nitrogen showed departures from linearity never greater than ⅓%, while tests over a month showed that air (reduced to normal temperature and pressure dry) gave oxygen readings with mean fluctuations of 0·15% while pure nitrogen read constantly to within the mean equivalent of 0·11% oxygen.

The output with 87·5 mA heater current is 3·75 mV on air (N_2 output = 0). This instrument was adjusted near to maximum $H(dH/dx)$ and is more sensitive within this range of concentration than one pair of chambers in the Oxford instrument. In the latter, sensitivity is sacrificed for a more extended useful concentration range. The air reading on the Oxford model is 3·2 mV using 100 mA heater current and two pairs of chambers.

(*b*) *The Oxford instrument.* This model is most frequently used coupled directly to a potentiometer recorder giving a range of about 0–60% oxygen concentration N.T.P. on the 10 mV full-scale deflexion Elliottronic recorder (0·15 in. on the chart represents approximately 8 mm of mercury partial pressure). Since these recorders draw no current from the source on balance, they can be remotely indicating without change in calibration owing to lead resistance, and have the further advantage that the additive electromotive force of the two pairs of thermocouples is not reduced by the doubled internal impedance.

Calibration by the Haldane gas analysis method gives the calibration curve of Fig. 4 and a scatter of individual points about the mean curve of less than ±4 mm of mercury partial pressure of oxygen. This is at least six times better than the thermal conductivity method over this range. The individual points plotted in Fig. 4 show the agreement between this instrument and oxygen concentrations determined simultaneously by a Beckmann–Pauling model S oxygen meter modified for continuous flow and to cover the range 140–780 mm of mercury partial pressure of oxygen and previously calibrated by gas analysis. Throughout the range, the agreement between the two instruments is better than ±8 mm of mercury partial pressure.

The departure from linearity is very small from 0–380 mm of mercury partial pressure and the useful range extends from 0–760 mm of mercury partial pressure without serious of sensitivity.

The calibration is independent of the direction of current flow through the heaters (i.e. they do not significa move in the field when the current is reversed). The bration remains the same with a.c. heating, though thi inadvisable since alternating stress on the fine wire will rec its life.

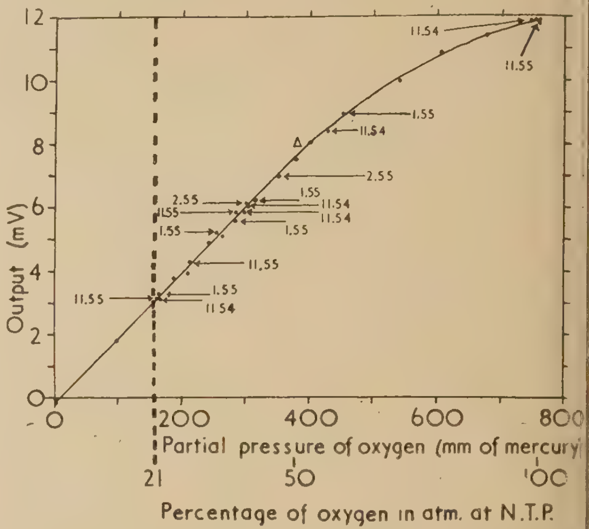


Fig. 4. Calibration of the Oxford instrument. (selection of the points are dated to illustrate long-term stability)

• oxygen, nitrogen mixtures; △ 50% oxygen, 50% carbo dioxide mixture.

4.2 *Response time.*

The shortest time in which the instrument will accura respond to a sudden change in oxygen concentratio determined by the maximum speed of flow of gas into chambers which will not disturb the convective proces This inherent speed of response can be achieved over a w range of gas flow in the main sampling tube by suita designing the manifold feeding the chambers.

The maximum speed of response of the Oxford instrum is about twenty seconds to 90% response and using particular manifold this response can be achieved with m sampling tube velocities from 100 ml./min up to 3 l./mi suitable rearrangements of the feed to the chambers. I better to blow the gas through the instrument and to k the mean pressure near atmospheric than to apply suctio

4.3 *Temperature coefficient.*

The instrument is temperature sensitive [$1/T_1^2$ term equation (1)] becoming more sensitive to the paramagn component with decreasing ambient temperature, tho factors other than the paramagnetism are involved. With temperature regulation or compensation the tempera coefficient of the ARL instrument is as illustrated (Fig. similarly, in the Oxford instrument a decrease in amb temperature of 1° C causes an increase in indicated pa pressure of about 1% of the true partial pressure. This be avoided either by enclosing the whole instrument i thermostatically controlled chamber (ARL), the gas rap attaining the temperature of the main mass of metal ord) by compensation with temperature-sensitive devices. circuit (Fig. 3) compensates accurately for all tempera- s between 5 and 30° C by means of a thermistor network ch suitably decreases the heater current with decreasing ient temperature. The voltmeter monitoring the heater s is also made temperature sensitive so that it must be to correct variation in the 12 V supply) to the same scale ing independently of ambient temperature. Its position the first thermistor network is most useful in that it itors whether that network is still working properly, the constancy of the instrument reading can rapidly be ked on outside air or cylinder oxygen and nitrogen.

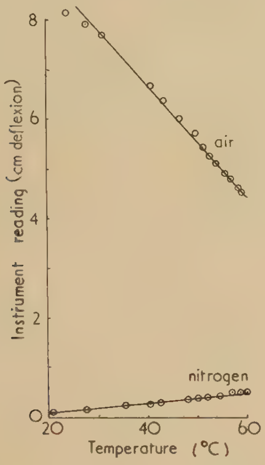


Fig. 5. Variation of instrument reading with temperature for A.R.L. model

many instruments were to be made, thermistor com- ation has the disadvantage that the temperature sensitive ork would probably require to be adjusted individually ch instrument. A thermostat box is simpler but requires power supplies and usually necessitates the controlled erature to be above any ambient temperature likely to ncountered, with some loss in achievable sensitivity due ecreased $1/T_1^2$ in equation (1). Thermistor control acts he $1/T_2^2$ term and, within limits, can retain the achievable itivity of lower ambient temperatures.

Sensitivity to the non-paramagnetic gas component.

xygen is the only normally encountered gas which is ngly paramagnetic (see the table), the rest being dia- netic with susceptibilities of magnitude two orders lower oxygen for the common gases. The normal and netically enhanced convective processes are the main rol of the temperature of the heaters, but thermal con- ivity of the gas also has an effect.

susceptibility of some common gases and their equivalent magnetic effect on the instrument

		1 atm of the gas is equivalent magnetically to oxygen concentration	
Gas	*Magnetic susceptibility 20° C 10^{-9} per cm³*	*% N.T.P.*	*mm of mercury partial pressure*
gen	+ 106	+ 100	+760
ogen	− 0·34	− 0·4	−2·7
on dioxide	− 0·42	− 0·6	−4·8
n	− 0·45	− 0·6	−4·5
c oxide	+48·7	+44·2	+335

The ARL instrument is likely to encounter hydrogen as an impurity in the gas sample and it is estimated that 2% hydrogen in air would introduce an error of ¼% in the oxygen reading.

In the Oxford instrument, designed mainly for physiological work, high carbon dioxide is sometimes encountered, and at 380 mm of mercury partial pressure of oxygen, the indication is 18 mm of mercury high, for the instrument calibrated on mixtures of oxygen and nitrogen (Fig. 4), if the whole of the remaining gas is carbon dioxide instead of nitrogen. This is not primarily a magnetic effect, since half an atmosphere of carbon dioxide, which is diamagnetic, is magnetically equivalent to only minus 2·4 mm of mercury partial pressure of oxygen and the same amount of nitrogen is equivalent to minus 1·3 mm of mercury partial pressure of oxygen. This sensitivity increase is due to the reduced thermal conductivity of carbon dioxide which is almost one-half that of nitrogen (oxygen and nitrogen have very similar thermal conductivities). The reduced convective cooling allows the wires to reach a higher steady state temperature, increasing the magnetic sensitivity to oxygen [equation (1)]. However, this behaviour is entirely satisfactory for physiological work when the total carbon dioxide content is unlikely ever to exceed one-tenth of one atmosphere.

The effect should be compared with the thermal conductivity method, where a change of carbon dioxide content is sixteen times more effective in changing the thermal conductivity of air than an equal change in oxygen concentration. Similarly, water vapour has a negligible effect on this instrument, though it is advisable to dry the gas sample to a lower dew point than ambient temperature to avoid condensation within the chambers. This is avoided automatically when the instrument is thermostatically maintained at a temperature higher than the highest ambient temperature. (Infant incubators frequently contain gas saturated at 35° C.) In the thermal conductivity method, water vapour changes are twelve times more effective than oxygen concentration changes.

4.5 *Pressure dependence.*

The calibration (indicated partial pressure) of these instruments is not independent of ambient pressure (for reasons indicated in Section 2), though the effect is negligible in the normal range of ground level atmospheric pressure changes. For larger pressure changes, such as the ARL instrument is likely to encounter, pressure compensation is necessary. In this instrument the calibrations for changes in oxygen content at constant pressure and changes in oxygen partial pressure due to changing total pressure (which are normally different), can be made the same by incorporating a pressure controlled variable resistor as a shunt to the indicating galvanometer. With an available pressure sensitive rheostat, identity of calibration was achieved between 110 and 171 mm of mercury partial pressure of oxygen, achieved either by varying the composition of the gas or the total pressure (Fig. 6). This useful range can be extended by designing a suitable law for the pressure variable resistance.

4.6 *Sensitivity to heater current: stability.*

A 5% change in heater current produces a 7% change in sensitivity, increasing with increasing current. If the heater current is maintained within ±1% the sensitivity remains constant within ±0·5%. The dated individual points in Fig. 4 show the long-term stability to be excellent (Oxford). Similarly, frequent testing of the ARL instrument over a period of one month showed that the mean fluctuation of the reading of the instrument on pure nitrogen was equivalent to ±0·11% atm of oxygen, the air reading variability was equivalent to ±0·15% oxygen and three tests on a 13% oxygen in nitrogen mixture gave a mean reading which departed from an assumed linear calibration nitrogen-air by the equivalent of ±0·25% oxygen.

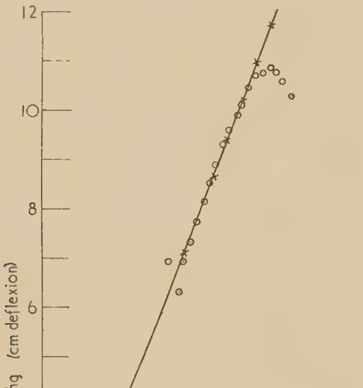


Fig. 6. Relative calibrations due to changes of oxygen content when total pressure equals 760 mm of mercury (×) and changes of oxygen partial pressure due to changes of total ambient pressure (⊙). Thermostated at 26·7 ± 2° C (A.R.L. model)

The instruments are robust and contain no moving parts. They are insensitive to vibration; possibly the only disadvantage of the Beckmann–Pauling meter is the fine quartz suspension of the test body which is somewhat delicate and sensitive to vibrations and, further, requires highly specialized manufacturing techniques.

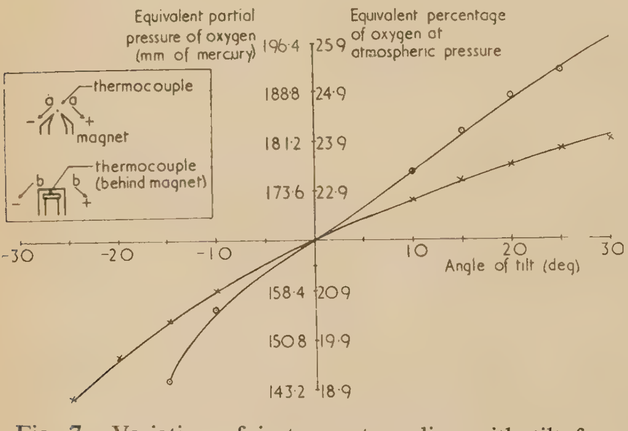


Fig. 7. Variation of instrument reading with tilt for A.R.L. model

○ tilt as shown by arrows *a*, *a* (inset);
× tilt as shown by arrows *b*, *b* (inset).

The instrument readings are somewhat sensitive to level Variations of reading of the ARL instrument with ang tilt are shown in Fig. 7; similarly the Oxford instrument be tilted up to ±10° to the horizontal along axis *XX* or along *YY* (Fig. 3) without changing the indicated pa pressure of oxygen by more than ±8 mm of mercury.

5. RESULTS (OXFORD MODEL)

To illustrate two applications of the instrument, Fig. shows a record of oxygen concentrations reached in a of infant incubator, sometimes used in emergency ambul services, at different rates of flow and different adjustm of the ventilation of the cot.

Fig. 8(*b*) shows the instrument recording oxygen centrations inspired by an animal in a closed contro atmosphere box (full curve). The dotted curve is a si taneous recording of the resulting changes in oxygen te in the tissue fluids of the animal, measured polarographi by subcutaneous Pt–Ag.AgCl$_2$ electrode systems.(16,17) instrument sensitivity is reduced to two-thirds in Fig. by a potentiometer, to enable 760 mm of mercury pa pressure of oxygen to be on the recorder scale.

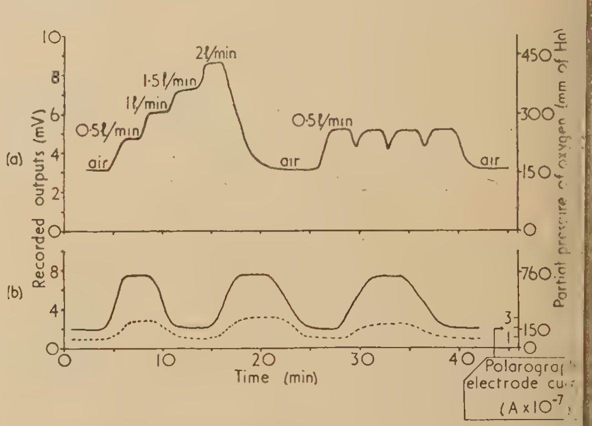


Fig. 8. Two applications of the Oxford instrumen

(*a*) Infant incubator. Oxygen flow rate to cot marked curve which shows output from paramagnetic oxygen me cot lid open 1 in. Sharp depressions in curve show rapid dr in oxygen concentration each time the "nursery" doo opened and closed.

(*b*) Animal in closed controlled-atmosphere box. Continu curve shows output from paramagnetic oxygen meter. Do curve shows output from subcutaneous polarograp electrodes.

ACKNOWLEDGEMENTS

To Prof. E. G. T. Liddell for the excellent facilities laboratory; Dr. R. V. Coxon for pleasant collaborati the physiological experiments and help with the gas ana Mr. G. Johnson who bored and milled the Duralumin b Mr. A. J. Tyrrell of Mullard for ready advice and he magnets. To Mr. A. Hobson and the staff of Adm Research Laboratory, Teddington, for first bringin Naumann paper and the Ormandy and Stollery th couples to my notice. (R. H.

To colleagues at A.R.L.; in particular Messrs. E. W. W. Rogulski and Mrs. Lewis for assistance in tests o equipment and suggestions on the design of the de block. The details of the ARL model are publishe permission of the Admiralty. (A.

REFERENCES

BANISTER, P., KAY, R. H., and COXON, R. V. *Lancet*, **267.ii**, pp. 777–780 (1954).

COXON, R. V., BANISTER, P. G., and KAY, R. H. *Recueil Trav. Chim. Pays-Bas*, **74.5**, p. 513 (1955).

HILL, A. V., see RABINOWITCH, I. M., and BAZIN, E. V. *J. Canad. Med. Ass.*, **16**, p. 638 (1926).

SHAKESPEAR, A. *Proc. Roy. Soc. A*, **97**, p. 273 (1920).

BERG, W. E. *Amer. J. Physiol.*, **149**, p. 597 (1947).

HERRALD, F. J. C., and MCMICHAEL, J. *Proc. Roy. Soc. B*, **126**, p. 491 (1934).

DAYNES, H. A. *Gas analysis by measurement of thermal conductivity* (London: Cambridge University Press, 1933).

PRITCHARD, F. W. *J. Sci. Instrum.*, **29**, p. 116 (1952).

(9) STEWART, A. T., and SQUIRES, G. L. *J. Sci. Instrum.*, **32**, p. 26 (1955).

(10) PAULING, L., WOOD, R., and STURDEVANT, C. O. *Science*, **103**, p. 338 (1946); *J. Amer. Chem. Soc.*, **68**, p. 795 (1946).

(11) NAUMANN, A. *Siemens-Z.*, **26** (3), p. 134 (1952).

(12) Unpublished Admiralty Research Laboratory Report.

(13) REIN, H. *Schr. Dtsch. Akad. Luftfahrtforschg.*, **11**, p. 1 (1939).

(14) LEHRE, E., and EBBINGHAUS, E. *Z. Angew. Phys.*, **2** (1), p. 20 (1950).

(15) EBBINGHAUS, E. *Z. Angew. Phys.*, **8**, p. 294 (1953).

(16) MEYER, J. S., FANG, H. C., and DENNY-BROWN, D. *Arch. Neurol. Psychiat.*, **72**, p. 296 (1954).

(17) KAY, R. H., and COXON, R. V. *Nature [London]*, **177**, p. 45 (1956).

Pirani gauge for operation up to a pressure of 10 mm of mercury

By J. H. LECK, M.Eng., A.M.I.E.E., and Dr. C. S. MARTIN,* University of Liverpool

[*Paper first received* 7 *December*, 1955, *and in final form* 10 *February*, 1956]

A modified Pirani gauge is described which makes the continuous reading gauge useful in the high pressure range without requiring a great rise in the wire temperature. It is well known that a reduction of the length of the hot wire increases the useful range but at the same time decreases the sensitivity. It is shown here that an adequate sensitivity, combined with a large range, can be obtained by placing artificial supports along the length of the wire so as to give, in effect, a large number of short wires in series. In this way a gauge useful up to a pressure of 10 mm of mercury with a wire temperature of only 50° C, can be designed.

now well known that the upper limit to the useful pressure e of the constant voltage Pirani gauge depends upon factors: (i) the temperature at which the hot wire ates[1,2,3]; (ii) the length of the wire[2,4]; and (iii) the n of the Wheatstone bridge network.[3] At a high ure the sensitivity falls not only because of the diminish- nolecular mean free path but also—and this is usually nore important—because of the fall in wire temperature. rate of fall of temperature is a function of all three of bove factors. This paper is confined to the description experimental study of the importance of the length of vire.

e relative importance of the radial heat conduction from vire through the gas falls as the wire is shortened (i.e. the osses become more predominant) making the temperature lependent upon conduction through the gas. Thus with ortened wire, the temperature, and hence the sensitivity, more slowly with increasing pressure. Unfortunately, peration of the Wheatstone bridge circuit is made more ult by a reduction of the wire length. The lower supply ge, smaller balancing resistors and out-of-balance nts in the Wheatstone bridge necessitates much more ate control and recording apparatus. In this paper it is nstrated that the advantages of high end losses can be ned by supporting a comparatively long straight wire at many equidistant points—in this case ten—along its length. This increases the end losses artificially by an order of magnitude without reducing the bridge constants by any substantial factor.

It must be remembered that, whatever the modifications, the scale shape with constant voltage can never be as good as with constant temperature operation. However, because it does not present a continuous record of pressure (except in the case of the rather complex automatic control circuits designed by Von Ubisch[5] and by Litting[6]) the constant temperature technique has only a limited application in practice.

GAUGE CONSTRUCTION AND ITS CALIBRATION CHARACTERISTICS

Fig. 1(*a*) shows the method of gauge construction used to increase the effective end losses. Tungsten wire, 0·001 in. diameter, was stretched across 1 mm nickel rods and spot-welded firmly to each. The nickel rods were firmly embedded into a glass rod which was clamped rigidly along the central axis of a 5 cm diameter cylindrical gauge envelope. Altogether four gauges of this type were constructed with the length of the individual elements 1·5, 5·0, 10 and 20 mm, the total number of series elements being ten, ten, four and two respectively. [A commercial Pirani gauge (by Metropolitan Vickers Electrical Co. Ltd.) comprising in effect, eighteen elements each 60 mm long of 0·001 in. diameter tungsten wire was also used to form a basis of comparison.] The electrical measuring circuit shown in Fig. 1(*b*) was used throughout the work. High stability resistors R_1, R_2 and R_3 enabled the resistance of the Pirani element to be measured accurately at all times. A sensitive microammeter (6 μA full-scale deflexion) with a variable series resistance was used to measure the bridge out-of-balance voltage. Calibration of the Pirani gauge was carried out on a simple vacuum plant comprising a mechanical backing pump and a diffusion pump in cascade. A U-tube differential oil manometer formed the reference gauge.

---

* Now at Instituto Torres Quevedo, Madrid.

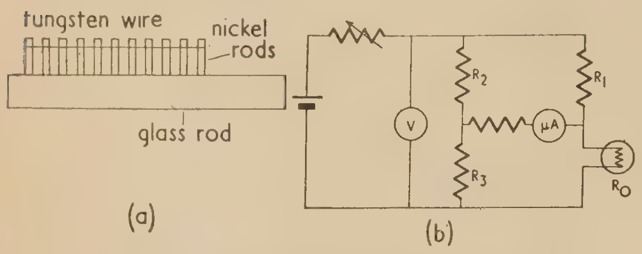


Fig. 1. (*a*) Construction of Pirani gauge element. (*b*) Circuit diagram of Wheatstone bridge

Some typical calibration curves are shown in Fig. 2 to illustrate the difference between the long, medium and short elements. A more complete comparison is made in Tables 1 and 2 which show the upper limit of the useful pressure range as a function of (*a*) the wire length, (*b*) the operating temperature, i.e. the wire temperature at zero pressure and (*c*) the bridge resistance ratio R_1/R_0. In order to make this quantitative comparison, the quoted value for the upper limit to the pressure range has been defined as the pressure at which the bridge output current reaches 90% of the saturation value. Thus the curves in Fig. 2 yield values of 800, 3400 and 10 000 μ for the 60, 10 and 1·5 mm wires respectively. Although this is a quite arbitrary definition it has the virtue of allowing a quantitative comparison to be made between all the calibration curves. For example, if the pressure scales

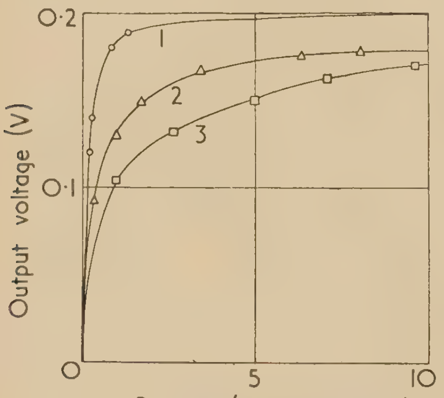


Fig. 2. Calibration curves for air

Wire operating temperature 50° C, $R_1/R_0 = \frac{1}{5}$. Curve (1), eighteen individual elements each 60 mm long, bridge voltage 4·75 V; curve (2), four individual elements each 10 mm long, bridge voltage 0·5 V; curve (3), ten individual elements each 1·5 mm long, bridge voltage 0·95 V. [Voltage scale ×20 for curve (2) and ×10 for curve (3).]

Table 1. *The upper limit to the useful working range o Pirani gauge as a function of both the length of the indi elements and the operating temperature*

Also given are the bridge output voltages and the resp times of the various gauges. All the results are for 0·0 diameter wire

Length of wire (mm)	R_1/R_0	*Operating temperature* (°C)	*Useful range* (μ)	*Output voltage* 90%	*Respon time* (s)
60	0·1	50	950	0·11	≃
	0·2	50	800	0·20	
	1·0	50	700	0·29	
	10	50	400	0·62	
20	0·1	50	2350	0·0016	≃
	0·2	50	1950	0·0086	
	1·0	50	1350	0·015	
	10	50	1200	0·033	
10	0·1	50	4000	0·0038	10
	0·2	50	3400	0·0083	
	1·0	50	3250	0·052	
	10	50	2450	0·084	
5	0·1	50	7100	0·0072	
	0·2	50	6800	0·0165	
	1·0	50	5700	0·044	
	10	50	4700	0·083	
1·5	0·1	50	—	—	15
	0·2	50	10 000	0·017	
	1·0	50	10 000	0·066	
	10	50	5 600	0·137	

Table 2. *The dependence of the useful range upon the ope temperature for wire elements* 1·5 *and* 10 *mm long*

Operating temperature (°C)	R_1/R_0	*Useful range* 1·5 mm	10 mm
25	0·1	11 700	3550
	0·2	10 500	3400
	1·0	7 650	2900
	10	6 250	2550
50	0·1	—	4000
	0·2	10 000	3400
	1·0	10 000	3250
	10	5 600	2450
100	0·1	—	5000
	0·2	—	4250
	1·0	—	3300
	10	—	2500
200	0·1	—	7000
	0·2	10 200	—
	1·0	5 300	—
300	0·1	—	9050
400	0·1	—	11 150

ırves (1) and (2) of Fig. 2 are expanded by a factor 0/800 and 10 000/3400 respectively the three curves then approximately the same shape.

Table 1 a comparison of the response times of the us elements is also made. This has been done by enly increasing the pressure in the vacuum system from to some fixed value and observing the time taken for the ıt current to reach 90% of the final value. Experiment ed the response time to depend upon the length of the ents, but to a first approximation upon neither the ating temperature nor the bridge arm ratio.

order to check the stability of the multi-element contion, the 1·5 mm element gauge was run (with $_0 = \frac{1}{5}$ and an operating temperature 50° C) conusly for 400 hours under varying vacuum conditions, alibration being checked at intervals during this period. consistent variation in the characteristic was observed, ugh there were some random variations amounting to 5% error in pressure reading in the range 2000 to 6000 μ a zero error of 2 μ.

DISCUSSION OF RESULTS

e experiments show very clearly the greater operating e obtained by reducing the length of the individual wire ents. This is most marked at wire temperatures less 100° C. For the long and medium elements (10 mm greater) the range for any given R_1/R_0 increases with asing operating temperature but for the very short mm) element the range is not increased appreciably even ıcreasing from 25 to 200° C (Table 2).

nple theory shows that there must be a limiting length, ction below which causes no further increase to the ıl range. The supports—which must be at a temperature le above ambient—act as small Pirani gauges and thus ence the temperature-pressure characteristic of the wire. effect is quite negligible for a very long wire but becomes and more important as the wire is shortened until ually it predominates. Thus the characteristics of an mely short wire are those of the massive supports r than of the wire itself (i.e. the range must be small ıse of mean free path considerations). All the above ts show that the limit is not reached even at 1·5 mm, ugh the fractional improvement by the reduction in h from 5 to 1·5 mm (i.e. by a factor of 3·3) is less than gained by the reduction from 10 to 5 mm (by only a r of 2). Thus there is probably no advantage to be d below 1·5 mm for a wire 0·001 in. diameter. With a er wire, the useful limit can probably be extended below ı although the construction would be extremely difficult. wires longer than 5 mm there is no advantage to be d by reducing the wire diameter. Some measurements during the present series of experiments showed that ements 5 mm long there was no change in the range of than ±10% by reducing the wire diameter from 0·001 004 in. Any improvement, because of the smaller mean ath/wire diameter ratio for the thinner wire, was offset e lower end losses/heat conduction ratio.

values of gauge sensitivity quoted in Table 1 are the output voltages at 90% saturation (assuming, of course, a balanced bridge at zero pressure). They apply only when the output meter resistance is large compared to that of the four Wheatstone bridge arms.

Introducing the intermediate supports along the wire unfortunately increases the thermal inertia of the system (because of the slight variation of temperature with pressure) and therefore the time taken for the wire to reach equilibrium after a sudden change of pressure. The observations showed this to be very important for the shortest wire, but, as may be anticipated, much smaller for the 10 and 20 mm elements (Table 1).

CONCLUSIONS

For many applications a multiple wire construction with each element 10 mm long instead of the more usual long wire may be adopted to increase the useful operating range without introducing any serious disadvantage. The gauge can be useful up to a pressure of over 3 mm of mercury for a mean wire-temperature of only 50° C. A further extension can be made to 10 mm of mercury by shortening the individual elements to 1·5 mm. Unfortunately, there is now the disadvantage of a very much increased time constant. The construction of a multi-element gauge is not difficult, provided the spot-welded connexions are made with care. Once the construction has been completed the unit is more robust than a simple long element of the same diameter.

The advantage of the low temperature short element is probably greatest in applications where corrosive gases may attack the wire at high temperatures. (It must be noted that the mean values of temperature are quoted in this paper, the maximum temperature—at the centre of the element—will be higher by as much as 50 to 100% for the shortest wires.)

The number of series elements can be chosen in order to give an adequate signal for the particular output meter to be used. The numbers in this work are adequate to give a full-scale deflexion on a commercial robust panel-mounting microammeter at the maximum useful pressure.

ACKNOWLEDGEMENTS

The help of Prof. Craggs and Prof. Meek in the preparation of this paper is gratefully acknowledged. One of us (C. S. M.) would like to thank the "Patronato Juan de la Cierva" of Madrid, Prof. Meek and the authorities of the University of Liverpool who provided the facilities for his work at Liverpool.

REFERENCES

(1) DUNOYER, L. *Vide*, Nos. 20, 21, 22, 23 (1949).
(2) VON UBISCH, H. *Appl. Sci. Res. A*, **2**, pp. 364, 403 (1951).
(3) LECK, J. H. *J. Sci. Instrum.*, **29**, p. 258 (1952).
(4) MOLL, W. J. H., and BURGHER, H. C. *Zeits Tech. Phys.*, **21**, p. 199 (1940).
(5) VON UBISCH, H. *Nature* [*London*], **161**, p. 927 (1948).
(6) LITTING, C. N. W. *J. Sci. Instrum.*, **32**, p. 91 (1955).

A modified bridge earthing device

By B. Berger, B.Sc., Graduate I.E.E., C. A. Parsons and Co. Ltd., Newcastle upon Tyne, 6

[*Paper received* 22 *December*, 1955]

A method is described for eliminating the effects of stray impedance in an a.c. Wheatstone bridge. Whereas the Wagner earthing device uses two auxiliary branches, the modified device uses an auxiliary source of supply. The elimination of the auxiliary impedances is of advantage in a high-voltage bridge.

Brief practical details of the device are given for a 50 c/s Schering bridge. The device is used to study the influence of stray capacities when such a bridge is applied to a transformer manufacture process.

The Wagner earthing device, if applied to a high-voltage four-branch impedance bridge, suffers from the disadvantage that one of the auxiliary branches (Z_5 in Fig. 1) has to withstand almost the full high-tension voltage. Now the function of the variable auxiliary impedances Z_5, Z_6 is to transform the single supply voltage vector V_1 into two suitable components, such that by successively balancing the main and the auxiliary bridge the potentials of d to b and to earth are reduced to zero. An alternative method of resolving V_1 is to connect a low-voltage source of supply V_2, of the same frequency but variable in magnitude and phase, in series with the high-voltage source. Their common connexion is made the earth point e (Fig. 2). Instead of varying Z_5 and Z_6 for the auxiliary balance, the magnitude and phase of V_2 is varied. The great advantage of this method of connexion is that Z_5 is eliminated.

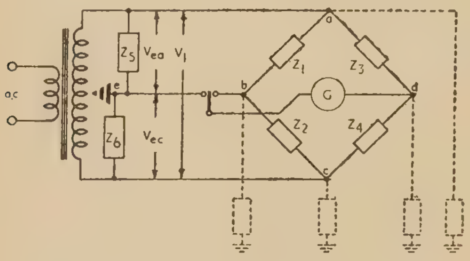


Fig. 1. Conventional Wagner earthing device

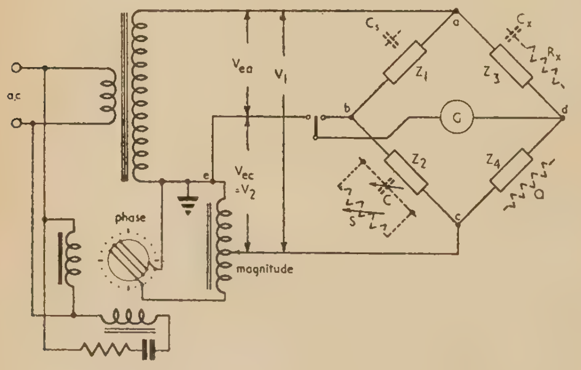


Fig. 2. Basic circuit of the modified earthing device

In general, only a few volts appear across the low-voltage arms of the bridge. Many simple ways of generating V_2 are therefore available in practice. The following are two of the circuits which were tried: a phase shifting transformer followed by a Variac; a Variac supplying a resistance capacitance phase shifter. The apparatus required co only of ordinary radio components. A resolver magsli used as the phase-shifting transformer.

A typical result using a Schering bridge

Test voltage = 5 kV r.m.s. Frequency = 50 c/s.
$C_s = 0{\cdot}001\ \mu$F. $Q = 50\ \Omega$.

Test condition	S (Ω)	C (μF)	C_x (μF)	
Without earthing device	400·7	0·111	0·008 01	0
Without earthing device. 0·25 μF connected between d and earth	400·8	0·140	0·008 02	0
With earthing device. 0·25 μF connected between d and earth	400·9	0·111	0·008 02	0

Bridge accuracy = $C_x \pm 0{\cdot}2\%$ tan $\delta \pm 1\%$

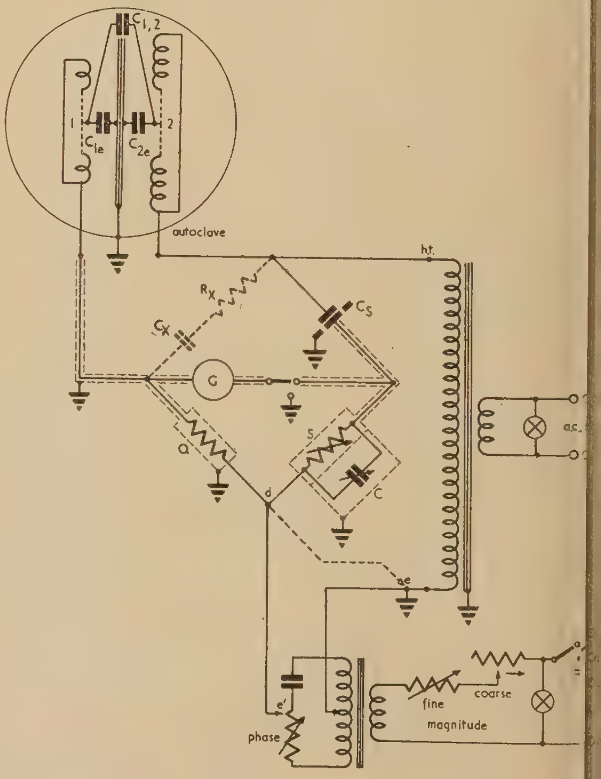


Fig. 3. H.V. Schering bridge test on a large po transformer

he device has been used on a 50 c/s Schering bridge at ages up to 5 kV. To test its efficiency artificial "stray" edances were connected from the corners of the bridge to th. A typical result is given in the table.

he fact that one point of the supply transformer must be thed is useful since many pressure testing transformers are alled with one end of the winding permanently earthed.

n interesting industrial application of the Schering bridge urs in the vacuum drying and oil impregnating of large ver transformers. Here the bridge is used to "monitor" dielectric state of the insulation as the process progresses.*

earthing device was used to check the accuracy of the dge regarding the influence of stray capacities. These y capacities arise in three ways: (i) the stray capacities in bridge itself; (ii) the earth capacity of the long screened which joins the transformer to the bridge (Fig. 3); (iii) the earth capacity of the low-voltage winding (Fig. 3). Without the earthing device, the stray capacities (ii) and (iii) shunt Q and hence give rise to a tan δ reading which is high. For power transformers, with a 50 c/s bridge having a standard condenser of 0·001 μF capacity, Q lies in the range 50 to 1000 Ω (for convenient values of the balancing decades S and C) and the error is negligible. A fault condition however, for example a damp or defective screened lead, immediately becomes apparent when readings with and without the earthing device are taken (*de′* taken to *de*).

Fig. 3 also shows an alternative form of phase shifter when a three-phase supply is available.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. R. J. D. Pattison for carrying out some of the experimental work. The note is published by permission of the Directors of C. A. Parsons and Co. Ltd.

Rippon, E. C., *Proc. Instn Elect. Engrs*, **101** (II), p. 437, Fig. 11 54).

An oxygen-quenched Geiger-Müller counter

By Ing. D. Srdoč, The Ruder Bošković Institute, Zagreb, Yugoslavia

[*Paper received* 19 *July*, 1955]

Systematic investigations have been made to determine the best concentrations of mixtures of neon, argon and oxygen for filling self-quenching Geiger–Müller counters. Evidence is given of the quenching action of oxygen in mixtures with neon and argon. The life of such counters seems to be unlimited. A plateau 65 V wide with a 15% slope per 100 V has been obtained at $V_{op} = 400$ V. Cathodes of various materials have been used and it was found that copper, brass and aluminium, coated with colloidal graphite, are quite satisfactory. This is an advantage relating to halogen-quenched Geiger–Müller counters.

quenching action of oxygen in Geiger–Müller counters ms to be due to the numerous absorption lines of oxygen the range between 500 and 5000 Å A systematic investi- ion of mixtures of neon, argon, nitrogen and oxygen, been made to find the most suitable concentrations.

he apparatus used is shown in Fig. 1. Great attention paid to ensure good sealing of all parts of the apparatus; leakage rate obtained was less than 0·01 lμ/s. The tem was evacuated by an oil diffusion pump to a pressure of about 10^{-5} mm of mercury. The counter bodies were meanwhile baked at 350° C for 1 hour. The pressure was measured by the use of a mercury manometer, a silicon oil manometer, and thermoelectric and Penning vacuum gauges. Spectroscopically pure argon and neon were used. Oxygen was prepared by electrolysis and dried in a liquid air trap. Commercial nitrogen was used after passing through a quartz tube containing red-hot copper filings to remove oxygen. The gases were quickly and thoroughly mixed by repeatedly raising and lowering a mercury reservoir.

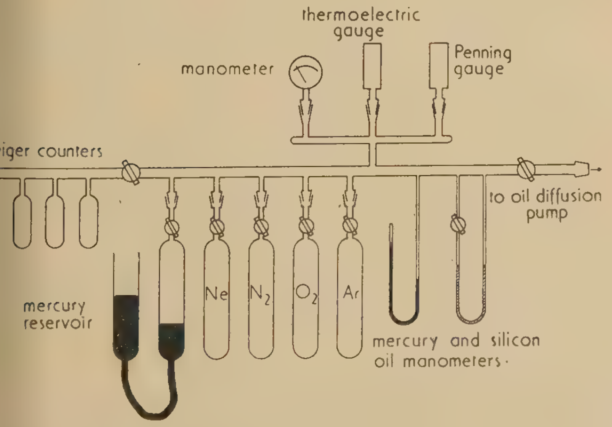


Fig. 1. Schematic diagram of vacuum system

The counter envelopes were made of soft glass, and the cathodes of copper, brass, aluminium and stainless steel, covered by a thin layer of colloidal graphite (Aquadag).

The dependence of the threshold voltage upon the gas mixture was investigated while the counters were still connected to the filling apparatus. The plateaux values and the life were measured on sealed-off counters with a ratemeter. A scaler was used as a control instrument. The counter series resistance was 10 MΩ.

The results of measurements can be summarized as follows. Counters filled with pure neon with admixture of oxygen did not show Geiger pulses when viewed on an oscilloscope. Such pulses, however, appeared with the addition of small amounts of argon, or nitrogen. Counters filled with neon (to a pressure of 25 cm of mercury), nitrogen (4 mm of mercury) and oxygen (1 mm of mercury) gave typical Geiger pulses, but a very short plateau of only 20 V at $V_t = 400$ V.

No detailed investigations with these kinds of mixtures have been undertaken.

Counters filled with neon, argon and oxygen, however, gave reproducible and encouraging results. These counters began to give typical Geiger pulses at a partial pressure of oxygen of about 0·4–0·6 mm of mercury; this pressure depended on the geometry of counters and on the partial pressure of the other gases. Below this value pulses had a shape similar to those shown in Fig. 2. Oscillations below V_t which are typical of the halogen counters with a small percentage of halogen have not been observed. A further increase of partial pressure of oxygen to about 1–1·5 mm of mercury gave a more flat and wide plateau. Higher pressures of oxygen increased the threshold voltage, but resulted in no improvement in counter characteristics.

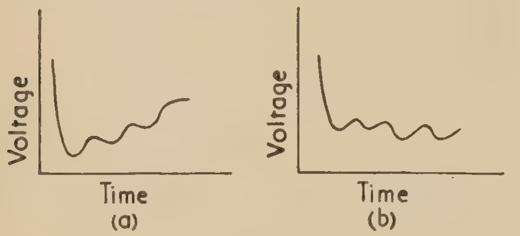


Fig. 2. Shape of pulses viewed on oscilloscope: (*a*) with a percentage of oxygen just below a critical value; (*b*) with a lower percentage of oxygen

Partial pressure of argon has also a critical lower value, which is about 2·5 mm of mercury, depending on the same factors as in the case of oxygen. An increase of the partial pressure of argon above 4–5 mm of mercury also incr V_t without improvements of counter characteristics. De relations between V_t and pressures of argon and oxyge given in Figs. 3 and 4. Measurements were taken i range of pressures where counters gave Geiger pulses. accuracy of measurement of voltages was ±2% ar pressures was ±2·5%.

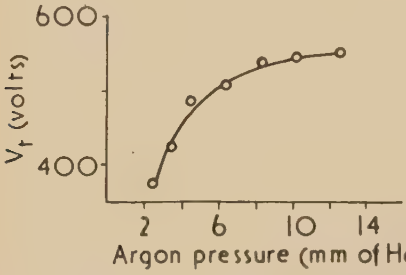


Fig. 3. Variation of threshold voltage V_t with partial pressure of argon (partial pressure of oxygen constant)

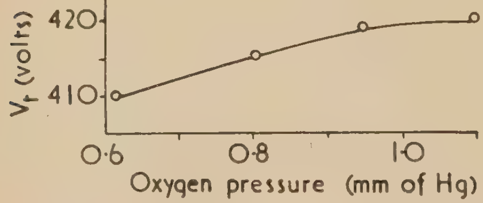


Fig. 4. Variation of threshold voltage V_t with partial pressure of oxygen (partial pressure of argon constant)

CHARACTERISTICS OF OXYGEN COUNTERS

A typical plateau curve is shown in Fig. 5. Attai plateaux were about 12–15% of threshold voltage. L oxygen counters seemed unlimited by use. The values and plateau measured after 10^9 pulses were the same as beginning of counting. A counter with V_t = 400 V w at 1500 V for 24 h and no damage was observed. Te ture variations of V_t between −78 and +140° C we than 0·25% for all kinds of oxygen counters that were t

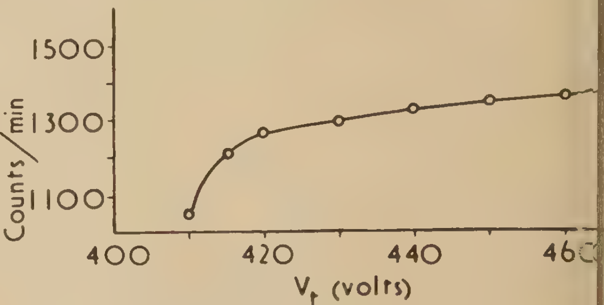


Fig. 5. A typical plateau of oxygen-quenched cou

The dead time of the oxygen counters was of the magnitude as that of the halogen counters.

CONCLUSIONS

Advantages of oxygen counters are:

(i) cathodes can be constructed of copper, bra aluminium without adverse effects on the counter life;

(ii) counters do not exhibit any observable chan values of V_t, plateau and slope of the plateau after 1 more counts;

(iii) using oxygen is easier than halogens;

(iv) the temperature coefficients of V_t and pulse amp are negligible.

The disadvantages of oxygen counters are a relatively plateau with a steep slope. However, with the use of supplies with a good voltage stabilization (e.g. those corona stabilizer), these disadvantages can easily be come.

ACKNOWLEDGEMENTS

I express my gratitude to my colleagues at the Elec Department of the Ruder Bošković Institute who help making all the necessary electronic equipment.

An input amplifier for a pulse-height analyser

By A. Folkierski, Ph.D., Imperial College of Science and Technology, London, S.W.7

[*Paper first received* 3 *August, and in final form* 29 *November*, 1955]

The design described incorporates two facilities important in the study of γ-ray spectra. Firstly, the analyser can be gated by pulses occurring simultaneously with the pulses to be measured. Secondly, the scale can be expanded. Errors introduced by the gate do not exceed 1% of the maximum output pulse-height.

instrument described in this paper was developed to t specific requirements which arose in the study of γ-ray tra, with the use of a fifty-channel pulse-height analyser. uch studies γ-rays passing through a scintillating crystal luce light pulses, and a photomultiplier converts these electrical pulses. Under suitable conditions the pulse-ht is proportional to the energy of the γ-ray, and thus a y energy spectrum can be obtained.

he specific requirements were:

) that the analyser could be gated by pulses occurring simultaneously with the pulses to be measured;

) that the scale of the analyser could be expanded.

first requirement arises in coincidence counting, when those pulses of the spectrum are of interest which occur ıltaneously with some other radiation detected by a ırate counter. Alternatively, it may be required to nine only a part of the spectrum, as described by Devons, ıning and Bunbury.(1) In that case the incoming pulses, de being fed into the input amplifier described here, are fed into a single-channel pulse-height analyser, whose out is used to gate the fifty-channel analyser, so that only es lying in a certain voltage range are admitted. The ond requirement follows from the fact that it is sometimes venient to examine some part of the spectrum in detail. the channel-width of the fifty-channel analyser is fixed, only way of doing this is to increase the gain in front of analyser. In addition, however, it is then necessary to ove the bottom part of the spectrum, so as to bring the resting part into the range of the analyser.

was further decided to include an amplifier in the instru-t, so that the latter together with the analyser, which pted pulses in the range 0–50 V, should form a self-ained system.

GENERAL DESCRIPTION

ig. 1 is the block diagram of the instrument.

he positive input pulse, of up to 6 V, is delayed by 5 μs delay line, and is passed through an attenuator into an lifier with a fixed gain of ×(+150). The pulse is then into a phase inverter whose gain is ×2. The resulting tive pulse, whose amplitude must not exceed 100 V, is fed into the gate.

rom the gate the pulse may be passed through either of channels, *A* and *B*. Channel *A* is an amplifier with a of ×(−0·5). Channel *B* contains a voltage subtractor an amplifier of gain ×(−2·5). The subtractor enables ltage of up to 100 V to be subtracted from the pulses that e through the gate. By this means the upper part of a trum of pulses can be made to occupy the complete ıge range of the analyser provided that that part is not than 20% of the total pulse-height range. The output es from either channel are positive and must not exceed 50 V; they are fed through a cathode follower into the analyser.

The gate is operated by either positive or negative gate-triggering pulses whose amplitude must be greater than 10 V. Each triggering pulse opens the gate for 12 μs. This duration, together with the delay introduced by the delay line, fixes the maximum rise-time of the pulses to be measured at about 7 μs; this is the case when the triggering pulse and the pulse to be measured arrive simultaneously. The minimum rise-time is determined by the composite rise-time of the amplifiers, which is adjusted to 1 μs. The delay is as long as 5 μs to enable slow pulses to trigger the gate in time. Provision is made for the gate to be held shut or open independently of triggering pulses.

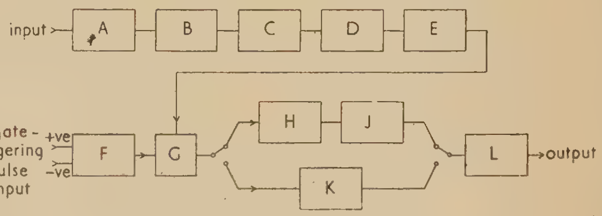


Fig. 1. Block diagram

A, input cathode follower; *B*, delay line; *C*, attenuator; *D*, *x*(+150) amplifier; *E*, phase inverter; *F*, pulse shaper; *G*, gate; *H*, voltage subtractor; *J*, *x*(−2·5) amplifier; *K*, *x*(−0·5) amplifier; *L*, output cathode follower.

DETAILED DESCRIPTION

Fig. 2 is the complete circuit diagram. The input cathode follower (V_1, V_2) is of conventional design; similar cathode followers are used in front of the attenuator and in the output. The delay line contains 37 T-sections, and the impedance is 4·7 kΩ. The line is terminated at both ends, which introduces an attentuation of the signal by a factor of 2. The attenuator is made up of high stability resistors and is switched. The available gains are: ×1, ×0·5, ×0·2 and ×0·1. The low output impedance of the preceding stage enables resistors of low value to be used, which in turn provides for constant attenuation in the required frequency range.

The ×(+150) amplifier is a ring-of-three feedback amplifier (V_5, V_6, V_7). A comparison of the actual gain (150) and the feedback ratio (1 : 205) indicates that the effective loop-gain is greater than 500, which is adequate to ensure reasonable stability.

The phase inverter is a single valve (V_8) virtual earth amplifier with a gain of ×(−2). The high-current pentode CV2127 is used in order to keep the output impedance low; this is necessary to reduce the danger of capacitive pick-up of the gating pulses.

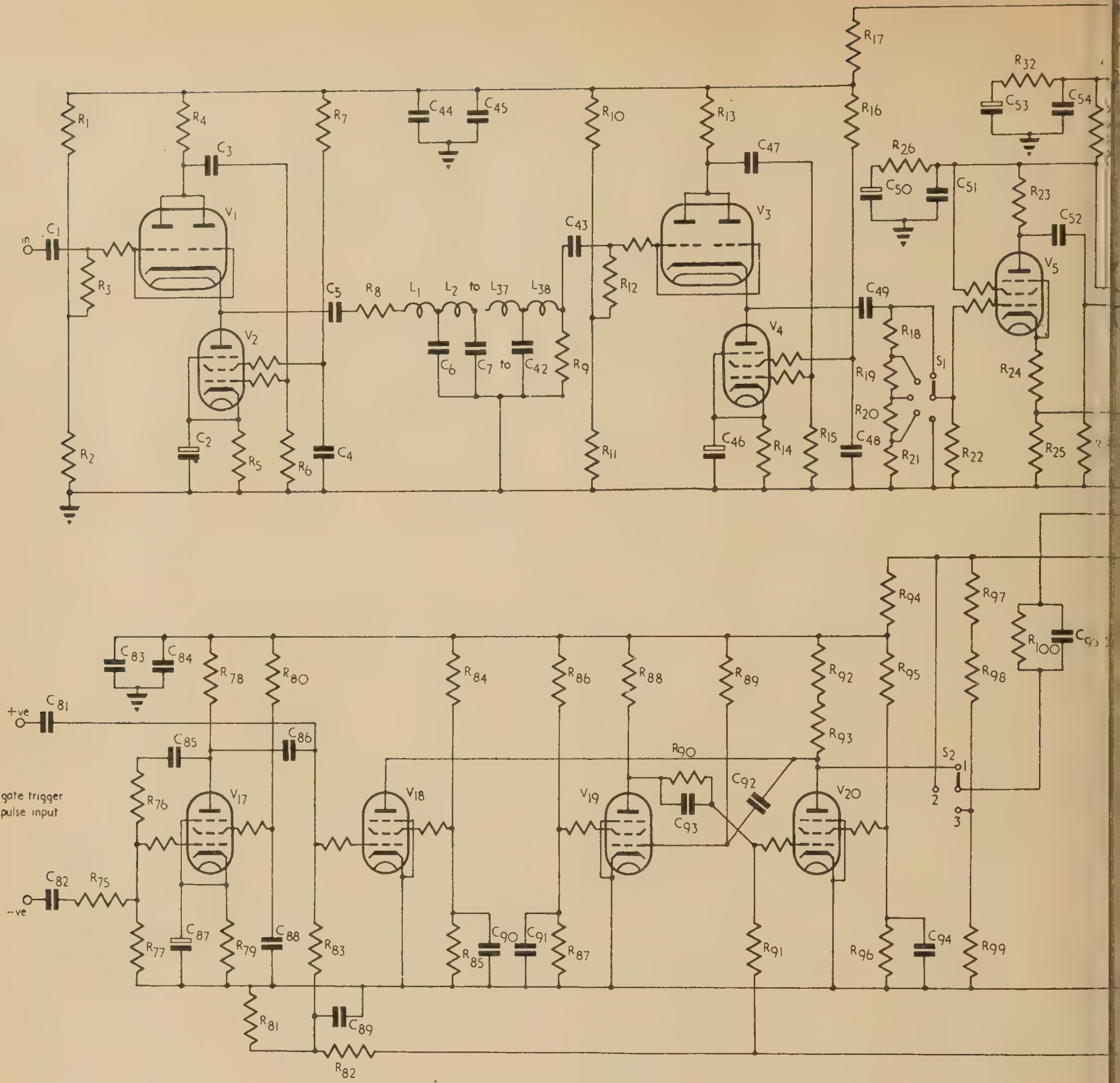

in
C1
R1
R2
R3
R4
C3
V1
V2
C2
R5
R6
R7
C4
C44
C45
C5
R8
L1
L2 to L37
L38
C6
C7 to C42
R9
C43
R10
R11
R12
R13
C47
V3
V4
C46
R14
R15
R16
R17
C49
R18
R19
R20
R21
S1
C48
R26
C50
C51
R32
C53
C54
R23
C52
V5
R24
R22
R25
+ve
C81
C83
C84
R78
R80
C85
C86
gate trigger pulse input
R76
V17
C82
R75
-ve
R77
C87
R79
C88
R83
R81
C89
R82
R84
V18
R85
C90
C91
R86
R87
R88
R89
V19
R90
C92
C93
R91
R92
R93
V20
S2
1
2
3
R94
R95
R96
C94
R97
R98
R99
R100

Fig. 2. Circuit diagram

R_1, R_2 = 330 kΩ
R_3 = 100 kΩ
R_4 = 2·2 kΩ
R_5 = 1·5 kΩ
R_6 = 470 kΩ
R_7 = 15 kΩ
R_8 = 4·7 kΩ
R_9 = 3·3 kΩ
R_{10}, R_{11} = 330 kΩ
R_{12} = 100 kΩ
R_{13} = 2·2 kΩ
R_{14} = 1·5 kΩ
R_{15} = 470 kΩ
R_{16} = 15 kΩ
R_{17} = 1·5 kΩ
R_{18} = 5·1 kΩ h.s.
R_{19} = 3 kΩ h.s.
R_{20}, R_{21} = 1 kΩ h.s.
R_{22} = 470 kΩ
R_{23} = 20 kΩ w.w.
R_{24} = 150 Ω h.s.

R_{25} = 68 Ω h.s.
R_{26} = 10 Ω
R_{27} = 470 kΩ
R_{28} = 4·7 kΩ
R_{29} = 20 kΩ w.w.
R_{30}, R_{31} = 68 Ω h.s.
R_{32} = 10 Ω
R_{33} = 2 kΩ w.w.
R_{34} = 7 kΩ h.s.
R_{35} = 68 Ω h.s.
R_{36} = 51 kΩ h.s.
R_{37} = 100 kΩ h.s.
R_{38} = 220 kΩ h.s.
R_{39} = 5 kΩ w.w.
R_{40} = 270 Ω
R_{41} = 10 kΩ
R_{42} = 330 kΩ
R_{43}–R_{45} = 5 kΩ w.w.
R_{46} = 2·2 kΩ
R_{47} = 1 kΩ
R_{48} = 470 kΩ

R_{49} = 15 kΩ
R_{50} = 330 kΩ
R_{51}, R_{52} = 5 kΩ w.w.
R_{53} = 100 kΩ h.s.
R_{54} = 200 kΩ h.s.
R_{55} = 510 kΩ h.s.
R_{56} = 1 MΩ h.s.
R_{57} = 1 kΩ
R_{58} = 20 kΩ w.w.
R_{59} = 150 Ω
R_{60} = 15 kΩ
R_{61} = 200 kΩ h.s.
R_{62} = 100 kΩ h.s.
R_{63} = 1 MΩ h.s.
R_{64} = 1 kΩ
R_{65} = 20 kΩ w.w.
R_{66} = 150 Ω
R_{67} = 15 kΩ
R_{68} = 470 kΩ
R_{69} = 330 kΩ
R_{70} = 330 kΩ

R_{71} = 2·2 kΩ
R_{72} = 1·5 kΩ
R_{73} = 470 kΩ
R_{74} = 15 kΩ
R_{75} = 150 kΩ
R_{76} = 150 kΩ
R_{77} = 1 MΩ
R_{78} = 10 kΩ w.w.
R_{79} = 150 Ω
R_{80} = 15 kΩ
R_{81} = 4·7 kΩ
R_{82} = 100 kΩ
R_{83} = 470 kΩ
R_{84} = 10 kΩ
R_{85} = 50 kΩ w.w.
R_{86} = 10 kΩ
R_{87} = 50 kΩ w.w.
R_{88} = 10 kΩ
R_{89} = 1 MΩ h.s.
R_{90} = 220 kΩ
R_{91} = 100 kΩ

The gate is similar in design to that described by Wilkinson.(2) The gate (valves V_9, V_{10}, V_{11}) can best be described as two cathode followers, in parallel, feeding a common load. When V_{9b} is cut off, V_{9a} and V_{10} act as a conventional cathode follower. To secure this condition for negative-going pulses of up to 100 V amplitude the grid of V_{9b} must be kept at a potential of less than +100 V, which is the case when the switch S_2 is in position 3. The gate is then c
When the grid of V_{9b} is held at +200 V, the cathode c
is clamped and cannot follow negative excursions of the
of V_{9a}. Under such conditions (S_2 in position 2) the ga
closed. In position 1 of the switch S_2 the grid of V_{9b} i
coupled to the anode of V_{20}; the gate is normally close
is opened on arrival of a gate-triggering pulse, when the a

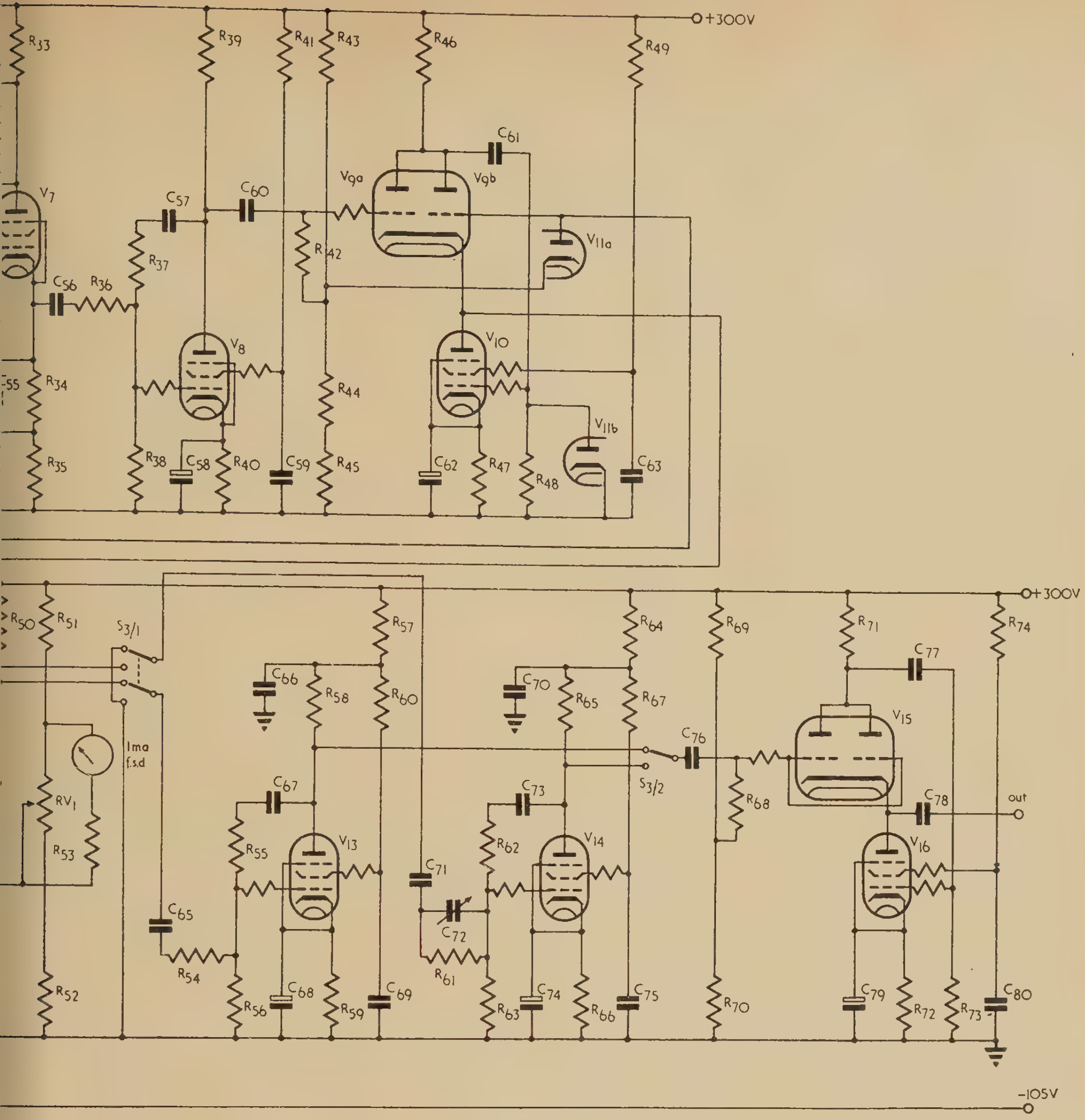

+300V
R33
R39
R41
R43
R46
R49
C61
V9a
V9b
V7
C57
C60
R42
V11a
C56
R36
R37
V8
V10
55
R34
R44
V11b
R35
R38
C58
R40
C59
R45
C62
R47
R48
C63
+300V
R50
R51
S3/1
R57
R64
R69
R71
R74
C77
C66
R58
R60
C70
R65
R67
V15
Ima
f.s.d
C76
S3/2
RV1
C67
C73
R68
C78
out
V13
V14
V16
R53
R55
R62
C71
C65
C72
R54
R61
R52
C68
R56
R59
C69
R63
C74
R66
C75
R70
C79
R72
R73
C80
-105V

Fig. 2. Circuit diagram (*continued*)

R_{92} = 1·5 kΩ w.w.
R_{93} = 5 kΩ w.w.
R_{94} = 470 Ω
R_{95} = 10 kΩ
R_{96} = 50 kΩ w.w.
R_{97} = 27 kΩ
R_{98} = 100 kΩ
R_{99} = 27 kΩ
R_{100} = 1 MΩ

RV_1 = 5 kΩ w.w.

C_1 = 0·1 μF
C_2 = 25 μF
C_3 = 0·01 μF
C_4 = 0·1 μF
C_5 = 0·01 μF
C_6–C_{42} = 30 pF
C_{43} = 0·01 μF
C_{44} = 0·1 μF
C_{45} = 0·001 μF

C_{46} = 25 μF
C_{47} = 0·01 μF
C_{48} = 0·1 μF
C_{49} = 0·01 μF
C_{50} = 8 μF
C_{51} = 0·002 μF
C_{52} = 0·05 μF
C_{53} = 8 μF
C_{54} = 0·002 μF
C_{55} = 50 pF
C_{56} = 0·01 μF
C_{57} = 0·01 μF
C_{58} = 25 μF
C_{59} = 0·1 μF
C_{60} = 0·01 μF
C_{61} = 0·01 μF
C_{62} = 25 μF
C_{63} = 0·1 μF
C_{64} = 0·01 μF
C_{65} = 0·01 μF
C_{66} = 0·1 μF

C_{67} = 0·01 μF
C_{68} = 25 μF
C_{69}, C_{70} = 0·1 μF
C_{71} = 0·01 μF
C_{72} = 2–8 pF
C_{73} = 0·01 μF
C_{74} = 25 μF
C_{75} = 0·1 μF
C_{76}, C_{77} = 0·01 μF
C_{78} = 0·1 μF
C_{79} = 25 μF
C_{80} = 0·1 μF
C_{81} = 22 pF
C_{82} = 0·01 μF
C_{83} = 1 μF
C_{84}, C_{85} = 0·01 μF
C_{86} = 10 pF
C_{87} = 25 μF
C_{88}–C_{91} = 0·1 μF
C_{92} = 22 pF
C_{93} = 33 pF

C_{94} = 0·1 μF
C_{95} = 40 pF

L_1 = 325 μH
L_2–L_{37} = 650 μH
L_{38} = 325 μH

V_1 = CV858
V_2 = CV138
V_3 = CV858
V_4–V_6 = CV138
V_7 = CV136
V_8 = CV2127
V_9 = CV858
V_{10} = CV138
V_{11}, V_{12} = CV140
V_{13}, V_{14} = CV138
V_{15} = CV858
V_{16}–V_{19} = CV138
V_{20} = CV2127
All grid stoppers = 100 Ω

$_{20}$ descends from +h.t. to about +50 V for 12 μs. The e V_{11a} prevents the grid of V_{9b} from rising above +200 V, n is the d.c. level of the grid of V_{9a}. Even so, the tion of the gate results in a small "pedestal" pulse at athode of V_9, due to change of current through V_{9a}. ninimize the importance of this effect, as well as the s due to the so-called contact potential of diodes, it is advisable to keep the amplitude of the gated pulses as large as possible.

The voltage subtractor consists of the double diode V_{12} and its d.c. biasing circuit. The anodes of V_{12} are connected together and are clamped at the level of the slider of RV_1 by the bottom diode. This level can be varied from +100 V to +200 V, the latter being the mean level of the cathode of

V_9. The difference between the two levels is read on the voltmeter and is the amount by which the amplitude of a pulse passing through the upper half of V_{12} is reduced.

The voltage subtractor in effect compares the d.c. voltage at the slider of RV_1 and the voltage of the cathode of V_9, which is a sum of the pulse voltage and the mean level at that point. It is important to consider the effect of the counting rate on the mean voltage level at the grid of V_{9a} (the valve V_{9b} is non-conducting whenever a pulse is being measured). In the limiting case of the grid of V_{9a} remaining at +100 V all the time, the change in the d.c. level at the bottom of its grid leak resistor would amount to approximately 1 V, that is, 1% of the maximum allowed pulse-height. The effect of the counting rate is therefore negligible.

As was mentioned earlier the output pulse may be derived either directly from the gate (channel *A*), or *via* the voltage subtractor (channel *B*). In the former case the output from the gate is passed through a virtual earth amplifier (V_{14}) of gain ×(−0·5) giving output pulses of up to 50 V. When the subtractor is used, its output is fed into a virtual earth amplifier of gain ×(−2·5); the output pulse is again positive and should not be allowed to exceed 50 V. Both amplifiers have a nominal loop gain of about 140 which ensures adequate stability.

The pulse-shaper for the gate comprises valves V_{17}, V_{18}, V_{19} and V_{20}. Valves V_{19} and V_{20} form a conventional univibrator which is shunt-triggered by the pentode V_{18}, normally cut off. A positive gate-triggering pulse switches on V_{18}. Valve V_{17} is a phase inverter, so that negative triggering pulses may also be used to switch on V_{18}. The duration of the gating pulse, which is derived from the anode of V_{20}, is controlled by the coupling condenser from the anode of V_{20} to the grid of V_{19} (C_{92}) and the grid leak resistor of V_{19}. The triggering pulse brings the anode of V_{20} from h.t. down to about +50 V in less than 0·3 μs. After 12 μs the anode returns to h.t. relatively slowly, so that the gate is fully closed only after a further 4 μs. The nominal "open period" of 12 μs can readily be reduced down to 5 μs by changing C_{92}.

The power supplies required for the unit are: 200 mA at +300 V d.c., electronically stabilized; 2 mA at −105 V d.c., neon stabilized; 7·4 A at 6·3 V a.c.

Precautions have to be taken to avoid capacitive pick-up of the large and fast gating pulses in the amplifier circuits. In particular, the delay line must be carefully screened.

PERFORMANCE

The output pulse amplitude is given by:

$$y = \alpha B(Cx - D)$$

when the voltage subtractor is used (channel *B*, switch S_3 in position 1). When the pulse is taken through channel *A* (S_3 in position 2) the expression becomes:

$$y = \alpha ACx$$

where

x = input pulse amplitude
y = output pulse amplitude
α = gain of the attenuator (1, 0·5, 0·2, 0·1, 0)
B = gain of amplifier in channel *B* (nominal 2·5)
A = gain of amplifier in channel *A* (nominal 0·5)
C = gain prior to the gate (nominal 150)
D = voltage subtracted (0–100 V).

Fig. 3 shows the γ-ray spectrum of ^{137}Cs, taken with a sodium iodide crystal. The output of the instrument (from channel *A*) was fed into an automatically swept, recor single-channel pulse-height analyser whose channel- was 2 V. Curve *A* was obtained with the gate perman open. Curve *B* was taken with the gate operated by output of an external discriminator, into which were undelayed, the measured pulses themselves. The d minator was adjusted so as to cut off the spectrum at a equivalent to 12·5 V at the output. The +0·5 V shift c gated spectrum is due to the pedestal effect, while the sli lower counting rate is due to the joint paralysis time c discriminator and the gate.

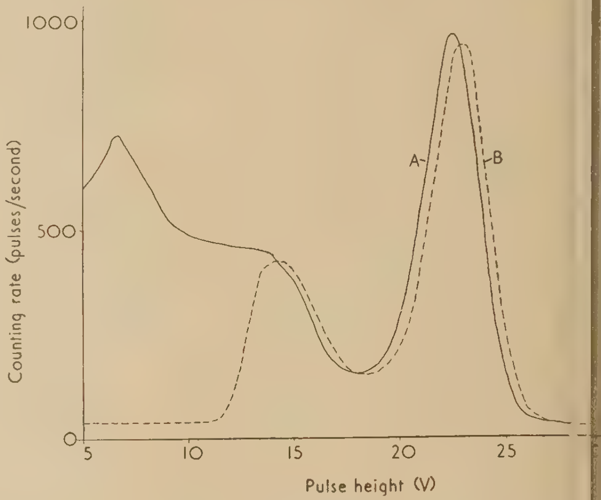


Fig. 3. Spectrum of ^{137}Cs

Fig. 4 shows the combined spectrum of ^{137}Cs and Curve *A* was taken through channel *A* and three peaks be seen, corresponding to γ-ray energies of 1·33, 1·17 0·67 MeV. The first two peaks are poorly resolved be the channel-width (2 V) amounted to about 0·1 Curve *B* was taken through channel *B* with the scale expa by a factor of about 2·3. The resolution was clearly proved. The counting rates should not be compared, a source positions were different in the two cases.

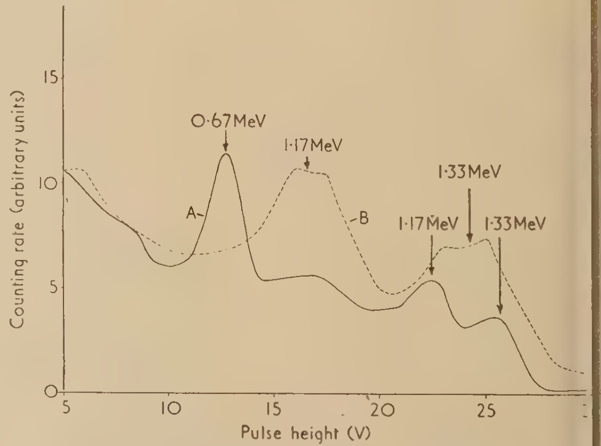


Fig. 4. Combined spectrum of ^{137}Cs and ^{60}Co

It will be seen that errors introduced by the gate d exceed 0·5 V at the output, and are in the nature of a the zero of the pulse-height scale. There exists also ther error (not apparent in the graphs), whose magnitude, le not exceeding 0·1 V at the output, varies with the tive delay of the measured and the gating pulses. This is to slight ringing in the delay line.

he gain of the instrument can be affected by temporal nges in the components and by variations in the a.c. ins voltage. The first effect was examined by taking spectra a fixed radioactive source at different times. Curves ained on different days showed that the gain changed by than 1%. This figure refers to the overall stability of the em including the photomultiplier supplies and the pulse-ght analyser. The mains voltage influences the gain dominantly through the heater voltage of valves. The ct is complicated and its amount depends on the particular ings of the controls. At worst, a 10% variation of the ins voltage is equivalent to a change of 0·7% in the input se-height. In practice the instrument, as well as the pulse-ght analyser, is fed from an automatically stabilized a.c. ply.

The instrument has been in constant use in this laboratory for over a year and has given completely satisfactory service. An account of some of the experiments carried out with its use appears in the paper by Devons, Manning and Bunbury mentioned earlier.(1)

ACKNOWLEDGEMENTS

The author wishes to thank Prof. S. Devons for constant support in the carrying out of this work.

REFERENCES

(1) Devons, S., Manning, G., and Bunbury, D. St. P. *Proc. Phys. Soc.* [*London*] *A*, **68**, p. 18 (1955).

(2) Wilkinson, D. H. *Proc. Cambridge Phil. Soc.*, **46**, p. 508 (1950).

A remote control apparatus for the movement of dosage measuring or similar equipment to indicated positions

By B. J. Perry, A.R.C.S., B.Sc., Ph.D., and N. H. Pierce, Westminster Hospital, London

[*Paper first received* 4 *January, and in final form* 6 *February*, 1956]

The mechanical and electrical features of this apparatus are described, with particular reference to ease and cost of construction. The relation of mechanical and electrical backlash to the accuracy of the whole system is discussed, and it is shown that some electrical backlash is essential in this simple type of servo-system. Its relation to position setting backlash and minimum inching distance is indicated.

e measurement in air or in a water phantom of the distri-ion of dose from a source of X- or γ-rays is often required hospital physics departments. It is convenient (and for ety, often essential) to have some form of remote control ich automatically positions the measuring chamber (or tillating crystal). In such an apparatus it is desirable that: the position of the chamber can be altered remotely in at t one plane; (*b*) the exact position of the chamber in this ne be indicated at the remote control position; (*c*) the mber will take up automatically any required position in plane; (*d*) the chamber will follow automatically any en isodose line in this plane.

he apparatus described here fulfills conditions (*a*), (*b*) (*c*) and is such that, with the addition on a separate el of relays and controls, it would automatically plot lose curves [condition (*d*)].

Iany details of the specification, and of the method of trol used, were determined by the need to keep costs imal. Thus movement and position indication were to confined to one plane only (in *X* and *Y* directions), the ge of movement being between 30 and 40 cm along each . The overall accuracy should be about ± 1 in 1000, that is the position of the chamber should be within ±0·5 mm of the position indicated at the remote control panel.

GENERAL DETAILS OF DESIGN

The most straightforward method of achieving the desired movements would seem to be in a servo-system using magslip type components. Alternatively, simple motor drives to each axis could be provided with a potentiometer circuit to indicate position. The latter was chosen as being the less expensive.

A block diagram of the apparatus is shown in Fig. 1. The voltage difference between the moving arms of a position-indicating potentiometer and its associated position-sensing potentiometer is amplified and made to operate the appropriate motor through either relay *A* or *B* in such a direction as to move the chamber carriage to a point corresponding to voltage balance. Alternatively either the position-indicating potentiometer or the motor can be adjusted by manually operated controls to achieve balance. The drive motors are small condenser-run induction motors (type RQR by the

Drayton Regulator and Instrument Co. Ltd.) which drive the lead screws, through a 25 to 1 worm gear, at approximately 100 rev/min. The lead screw pitch of 1 mm gives a chamber carriage speed of 10 cm/min. To achieve an accuracy of "within 1 mm" electrical braking was found to be necessary. It is obtained by passing 30 mA d.c. through each of the pairs of motor field coils immediately the alternating drive voltage is removed. As the need for simultaneous automatic control of both *X* and *Y* movements was considered very unlikely a saving was effected by making the amplifier and relay switching circuits common to both axes.

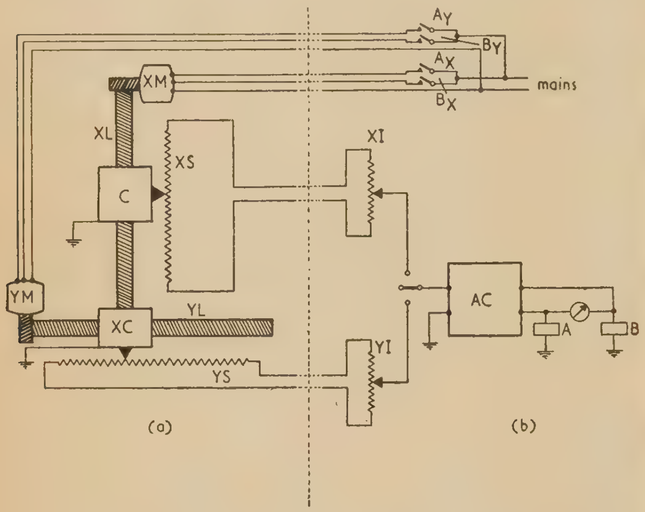


Fig. 1. Block diagram of remote control apparatus

(*a*) *X* and *Y* movements mounted on Dexion frame.
(*b*) Control circuits mounted on remote panel and chassis.

A, *B*, relays; *AC*, amplifier and associated circuits; *C*, chamber carriage; *XC*, *X*-axis carriage; *XI*, *YI*, position-indicating potentiometers; *XL*, *YL*, lead screws; *XM*, *YM*, drive motors; *XS*, *YS*, position-sensing potentiometers.

MECHANICAL DESIGN

Fig. 2 shows a section through the chamber carriage parallel to the *Y* axis. The carriage (1) runs on two silver steel rails (2) of circular cross-section. It is supported dynamically on two brass shoes (3) and a ball race (4). The lead screw (5) drives the carriage through the loosely fitting collar (6). The carriage is connected electrically to the *X* position-sensing potentiometer (7) by a modified P.O.3000 type relay spring set with a silver high current contact (8) shaped to minimum longitudinal contact on the potentiometer tra

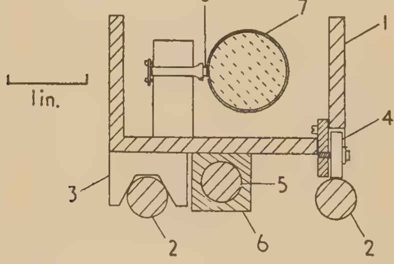


Fig. 2. Section parallel to the *Y* axis, through the *X* axis and the chamber carriage

Apart from its extra width, the *Y* carriage is identic the *X* axis chamber carriage, which it supports. The h rails are bolted directly to a Dexian frame, which also c the *Y* drive motor, *Y* position-sensing potentiometer, a shelf to take a water phantom. The layout of the com apparatus is shown in Fig. 3.

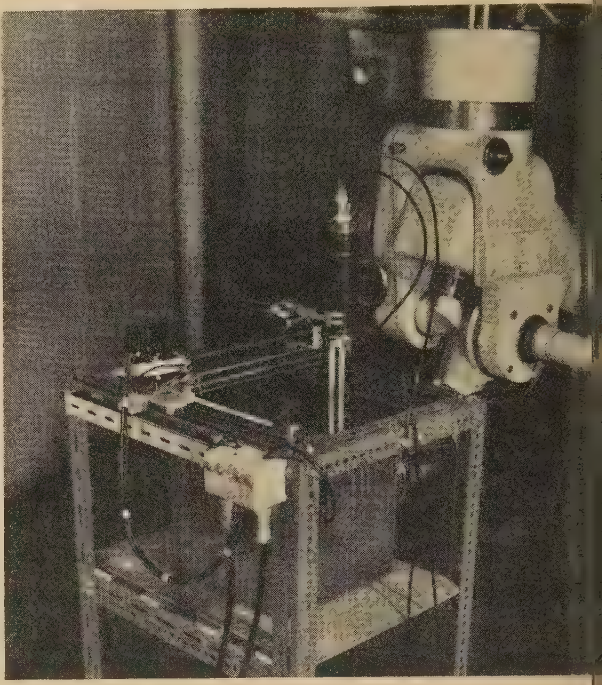


Fig. 3. General view of the apparatus set up with a tv crystal scintillation counter and water phantom for measurement of isodose curves from a cobalt 60 be therapy unit

ELECTRICAL DESIGN

In this type of servo-system there is very little to ch between d.c. or mains frequency for the control signal. use of the latter, however, does require careful desig avoid pick-up of small stray voltages in the bridge pa the circuit, and a phase-sensitive detector to operat motor control relays. The difficulties associated with signal centre around amplifier design. The signal level however, is fairly high (1 mm error equals approxim 0·1 V), and the response is slow (approximately 10 A d.c. signal was therefore chosen.

The potentiometers for both *X* and *Y* movement similar. The position-sensing potentiometers, made i authors' workshops, are wound from 34 s.w.g. enam Nichrome wire, 4 turns per mm wound on polished Pe rod of 1 in. diameter with the turns just touching. position-indicating potentiometers are a commercial corrected type CLR 8205 by Colvern which have a lin of better than ±0·1%. Two isolated 48 V supplies pr voltage for these potentiometer bridges.

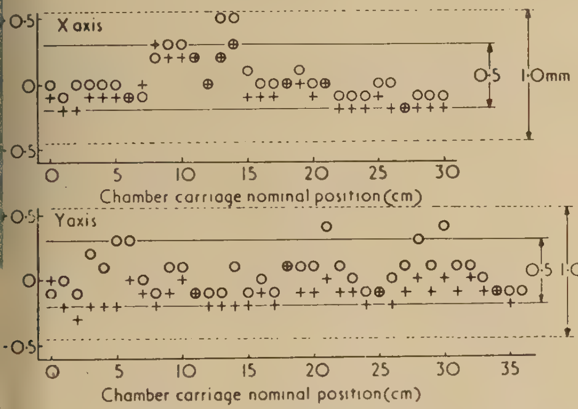
A conventional balanced two-stage amplifier, without back, is used, and is found to be sufficiently drift fre terminates in a cathode follower pair which were orig used to drive the relays *A* and *B*, but are now used to ıeter indication of lack of balance, and to drive two nitt flip-flop circuits. The two amplifier stages derive r high-tension from a highly stabilized supply.

he Schmitt circuits were found to be necessary because uncertainty in the point of operation, and operating ent backlash, associated with Post Office type 3000 relays. as also found that the relays, when driven by a cathode ›wer, could stay for some time in a half operated position. h the inductive load, and alternate a.c. and d.c. that the ys switch, this can cause excessive contact wear. With ys driven by the Schmitt circuits it is avoided. There is , however, backlash between the point of operation and ase(1,2) (see also Fig. 5) but it is of constant value and be adjusted electrically.

he remote controls for the whole apparatus are grouped ne small panel and chassis which is connected to the *X–Y* ıe by two six-core cables.

PERFORMANCE

he overall position-setting accuracy of the apparatus is vn in Fig. 4. The error in position as measured on a l metre scale is plotted against the nominal setting of the tion-indicating potentiometers. The points are seen to vell within the original accuracy limit of ±0·5 mm and in fact, mostly within ±0·25 mm of the mean value.



ig. 4. Overall position-setting accuracy (gain approximately 50% of hunting gain)

= points taken approaching balance from negative positions.
≒ points taken approaching balance from positive positions.

part from non-linearity in the potentiometers, the errors he system are forms of backlash. Mechanical backlash ıe lead screws and worm gear is fortunately immaterial. 'actor which also weighs heavily in favour of using this of control system.) The only mechanical backlash of sequence is that associated with the potentiometer moving :act. This, in practice, can be made negligible. Electrical klash, on the other hand, is essential for stability in this of servo-system where the speed of the correcting movet is constant and bears no quantitative relation to the r signal. The approach to balance and the effect of trical backlash at various values of amplifier gain is vn diagrammatically in Fig. 5. At low gain (*a*) there is nite backlash. As the gain is increased a point of no rall backlash is reached (*b*) changing to overshoot back- at (*c*) and eventually to hunting at (*d*). The circuit is nally operated between conditions (*b*) and (*c*) and the ıts of Fig. 4 were taken at approximately 50% maximum (or hunting) gain. As the gain increases from (*b*) to (*c*), although the overshoot backlash increases, the minimum inching distance continues to decrease. The table shows the variation of backlash and minimum inching distance as a function of gain for the *Y* axis of the apparatus. The overall stopping distance as calculated from these figures is between 0·25 and 0·3 mm corresponding to a stopping time of about 0·3 s. It can be seen, therefore, that the condition of minimum electrical backlash which occurs just prior to hunting does not normally correspond to a condition of minimum positional backlash.

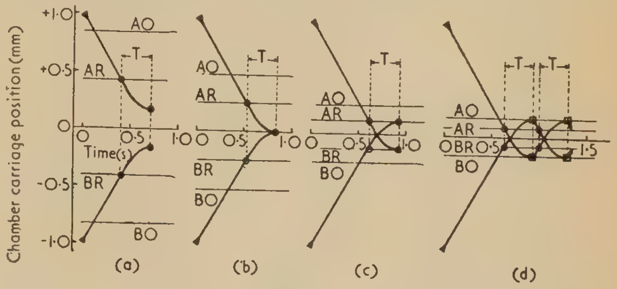


Fig. 5. The effect of amplifier gain on the approach to balance

(*a*) Gain 20%, backlash; (*b*) gain 33%, no backlash; (*c*) gain 67%, overshoot backlash; (*d*) gain 100%, hunting.
AO, relay *A* operates; *AR*, relay *A* releases; *BO*, relay *B* operates; *BR*, relay *B* releases.

○ = relays release.
□ = relays operate.
● = chamber carriage stops.
T = stopping time.

The effect of amplifier gain on overall positional backlash and minimum inching distance (readings taken on Y axis)

Relative amplifier gain	0·2	0·4	0·6	0·8	1·0*
Overall positional backlash (mm)	0·50	−0·03†	−0·17†	−0·26†	−0·26†
Minimum inching distance (mm)	1·30	0·77	0·63	0·56	0·50

* Any increase of gain over this value would normally cause hunting.
† The negative sign denotes overshoot backlash.

DEVELOPMENT

The circuit can be adapted to automatic dose contour following by the provision of a set of relays to switch movement from one axis to the other at each traverse of the balance position, the line followed by the carriage being a step approximation to the contour required. The circuit associated with the contour detecting head must be suitable for feeding a signal into the existing d.c. amplifier. In such an application the accuracy of operation depends on the detecting head circuitry rather than that of the control apparatus.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support given by the British Empire Cancer Campaign to the department in which the above apparatus was developed.

REFERENCES

(1) PUCKLE, O. S. *Time Bases*, 2nd ed., p. 81 (London: Chapman and Hall Ltd., 1951).
(2) BANTHORPE, C. H. *Electronic Engng*, **26**, p. 110 (1954).

Fine grain development in xerography

By K. A. Metcalfe, B.Met.E., and R. J. Wright, B.Sc., Defence Standards Laboratories, Woodville, South Aus

[*Paper received* 19 *July*, 1955]

Electrostatic images on xerographic plates may be developed by electrophoretic deposition from simply prepared suspensions of powders in certain high resistivity liquids. Prior milling of the powders in the liquids or in dispersing agents results in finer-grained developers. Virtually grainless images should be obtainable by development in colloidal suspensions.

In xerography⁽¹⁾ or electro-photography, an electrostatic image formed on selenium or other suitable material is subsequently developed by application of charged powder. Three methods of developing the latent image are known; these are referred to as the "cascade" and "powder-cloud" methods⁽²,³⁾ and liquid development⁽⁴⁾; cascade development is more appropriate for high contrast sharp line images, powder-cloud development produces excellent half-tone images with good latitude whilst liquid development may be controlled so that either high contrast or half-tone images can be obtained as required.

In each of these methods of development fine powder particles are used as the developing agent. In the cascade method, the active powder is mixed with an inert carrier powder (particle size -200 to 300 μ); in the powder-cloud method the active powder particles are dispersed in air. In liquid development the active powder particles are dispersed in liquids of high resistivity such as petrol (specific resistivity about 2×10^{16} Ω.cm),⁽⁸,⁹⁾ kerosene (about 1×10^{16} Ω.cm),⁽¹⁰⁾ carbon tetrachloride ($2{\cdot}5 \times 10^{17}$ Ω.cm) or mixtures of these liquids. Liquids of appreciably lower resistivity than the above such as acetone ($1{\cdot}82 \times 10^{7}$ Ω.cm) and chloroform (10^{10} Ω.cm) are not suitable. Liquid development offers better control than either of the dry processes, due principally to the more regular dispersion of the particles and to the inherent uniformity of the electrical charges on the particles.

Many powders disperse freely in the above liquids and in so doing acquire a charge, the sign of which is characteristic of the powder. For example, some types of carbon black dispersed in petrol acquire positive charges and are attracted to negatively charged latent images, whereas particles of the same powder if milled in linseed oil prior to dispersion in petrol, acquire negative charges. The process of liquid development is an example of electrophoretic deposition and the sign and magnitude of the charge should be primarily a function of the relative dielectric constants of the particles and the liquids,⁽⁵⁾ but may be changed by the environment of the particles at the time of dispersion, i.e. by the presence of other agents adsorbed on the particles. As an example, the presence of adsorbed moisture on monolite red particles causes a proportion of the particles to acquire negative charges and it is necessary therefore, in preparing xerographic developers from this pigment, to dry the particles prior to dispersion.

The main requirements for satisfactory liquid developers for xerography are as follows:

(1) the liquid dispersion medium must have high resistivity to avoid discharge of the latent electrostatic image on the xerographic plate;
(2) the powder particles should acquire similar charges when suspended in the liquid enabling them to be attracted to the electrostatic image;
(3) settlement of the particles should be as slow as possible and there should be no flocculation⁽⁶⁾;
(4) the particle size should be small.

Liquids fulfilling requirement (1) are readily obtained; p
and carbon tetrachloride are satisfactory in this regard
in addition their high vapour pressure enables the pla
be dried quickly. Particles suitable for dispersion in
liquids include pigments such as "monolite red R
"monolite yellow G.N.S.," "phthalocyanine blue," "wax
nigrosene," zinc oxide, carbon black, talc, "Hansa yel
and cadmium sulphide.

In liquid development of a xerographic plate, the par
adhering to the image will not normally be dislodged d
removal of the plate from the liquid. Excessive concentr
of powder in the liquid will lead, however, to exce
deposition of the powder on the plate and removal o
plate from the developer may then be accompanie
drainage of the excess deposit, causing impairment o
image.

The formation of deposits by electrophoresis m
investigated using the methods which Hamaker⁽⁷⁾ has ap
to the deposition of barium carbonate and other pow
from suspensions of these powders in liquids such as met
ethanol and acetone. Hamaker inserted two electrod
constant size and spacing in suspensions of this type
applied potentials up to 250 V across the electrodes
determined the relationships between weight of po
deposited on the electrodes and applied voltage, cur
concentration of powder in the suspensions and tim
deposition. In the present case when electrode size
spacing and applied voltage (about 10 000 V) are
constant and the concentration of the powder in a l
such as petrol is increased, it is found that the weigh
powder deposited on the electrode increases regularly u
a certain concentration; with greater concentration irreg

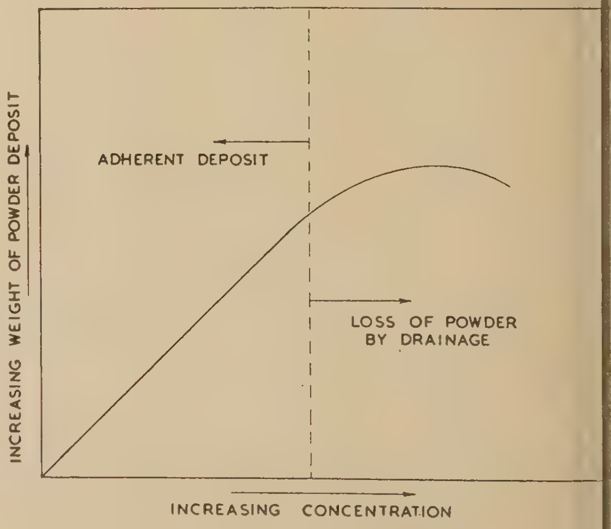


Fig. 1. Weight of powder deposit as a function
concentration of powder suspended in liquid

sition results owing to powder falling off under its own nt before and during removal of the electrode from the d. Deposition curves commonly take the form shown g. 1. For a given charge on the xerographic plate and a potential gradient in the developer tank, there is, fore, a limit to the density of the developed image, h depends on the charge of the particles and on their sive properties. The adhesive properties of particles sited by electrophoresis may be altered if desired by the tion of "binders."(8)

though direct shaking of many dry pigments with the e liquids gives dispersions suitable for the development easonably fine-grained images made up of particles in size range 1–15 μ, it has been found still finer-grained ges are obtained with all of the liquids quoted, if the dered material is ground in the dispersion liquid or in a us medium of high resistivity soluble in the dispersion d, such as linseed oil. Stable suspensions are readily ined in this way. A wide range of particles already d in viscous media is commercially available in the form tists' paints and printers' ink; in the latter, particle sizes to 2 μ are not uncommon. The fine-grained images ined by development of xeroradiographs in suspension ese materials are illustrated in Figs. 2 and 3; considerable nification of these images is possible without loss of ition. Fig. 2 is a xeroradiograph of a light switch loped in a developer produced by dispersing a "per- ent white" pigment—linseed oil mixture in petrol. 3 shows (at a linear magnification of ×100) a xerograph one hundred mesh Institute of Mining and Metallurgy .M.) screen developed with a carbon-black synthetic mixture dispersed in carbon tetrachloride (photo- hically "negative"). Xerographic plates may be developed ese "fine grain" liquid developers in four seconds or less, ime in many cases being dependent only upon the rate hich plates can be inserted into and removed from the loper.

cause the latent image on the plate is of an electrostatic re, it is believed that the resolving power of the xero- hic process will be limited only by the size of the particles to develop the image.(1) It has been found practicable ilize ultra-fine particles (approaching colloidal size) by lopment in the filtrate of developers prepared in the manner previously described and filtered through ordinary filter paper. Images have been obtained in this way which are of finer grain and are capable of greater enlargement than the finest grained photographic images.

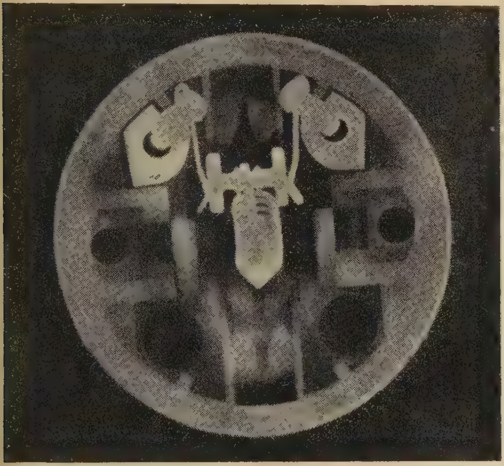


Fig. 2. Xeroradiographic image of light switch (×1)

rget-to-film distance, 3 ft; object-to-film distance, ¾ in.; exposure, 150 mA.s at 54 kV$_p$.

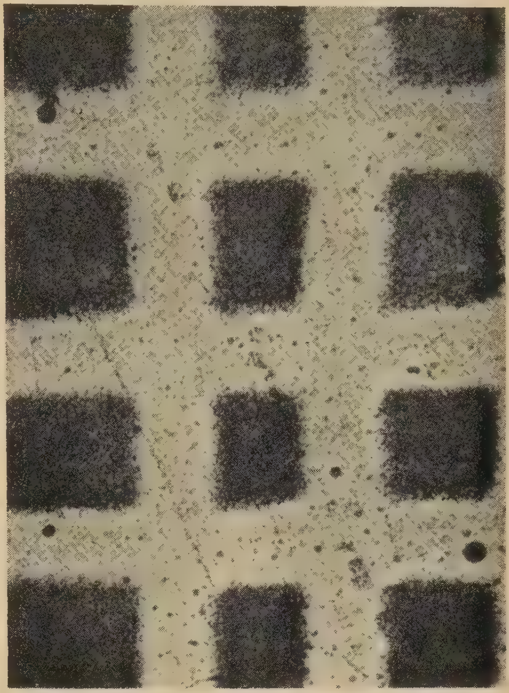


Fig. 3. Enlargement of xeroradiographic image of one hundred mesh I.M.M. screen (×100)

Target-to-film distance, 5 ft; object-to-film distance, 1¼ in.; target size, $\simeq 2 \times 2$ mm.

With a view to reducing the grain of the xerographic image still further, liquid developers using particles of colloidal dimensions are at present being investigated; such particles would be expected to be equally capable of electrophoretic deposition.

ACKNOWLEDGEMENTS

This paper is published by permission of the Chief Scientist, Department of Supply, Australia.

REFERENCES

(1) Schaffert, A. M., and Oughton, C. D. *J. Opt. Soc. Amer.*, **38**, p. 991 (1948).
(2) McMaster, R. C. *Non-destr. Test.*, **10**, p. 8 (1951).
(3) Oliphant, W. D. *Discovery*, **14**, p. 175 (1953).
(4) Metcalfe, K. A. *J. Sci. Instrum.*, **32**, p. 74 (1955).
(5) Creighton, J. H. *Principles and applications of electrochemistry*, 4th ed. (New York: John Wiley and Sons, Inc., 1947).
(6) Hamaker, H. C., and Verwey, E. J. W. *Trans Faraday Soc.*, **36**, p. 180 (1940).
(7) Hamaker, H. C. *Trans Faraday Soc.*, **36**, p. 279 (1940).
(8) Benjamin, M., and Osborn, A. B. *Trans Faraday Soc.*, **36**, p. 287 (1940).
(9) Conway, B. E. *Electrochemical Data* (Amsterdam: Elsevier Publishing Co., 1952).
(10) *Handbook of Chemistry and Physics*, 35th ed. (Cleveland: Chemical Rubber Publishing Co., 1953/4).

A switch-dial potential divider

By W. K. Clothier, B.Sc., M.E., A.Inst.P., Commonwealth Scientific and Industrial Research Organization,
Chippendale, New South Wales, Australia

[*Paper received* 11 *January*, 1956]

A new potential divider network is shown to represent a general class of divider of which the Varley slide is a special case. Another special case of particular interest is one in which the resistances of all dials are the same. In a decade divider of this type with a total resistance 10 r, only three values of resistance coil r, $r/9$ and $8r/9$ are required, or two values if the r's are made up from series pairs of $r/9$ and $8r/9$ coils. Since the errors due to contact resistance are small, the circuit is especially suitable for low-resistance dividers.

Many electrical measuring instruments and bridge circuits employ switch-dial potential dividers either of the Varley(1,2) or the Feussner*(2,3) type in order to provide fine subdivision of potential difference. These particular dividers have the important advantages that they are suitable for use as three-terminal networks and that the ratio of their output to input voltages can be adjusted throughout the range from 0 to 1. In these respects they are more versatile than some of the specialized dividing networks that have found application in d.c. potentiometers.(4)

In the Varley divider, Fig. 1, two coils of the first dial are shunted by the whole of the second dial, the combination having a resistance equal to one coil of the first dial. The second dial therefore subdivides a potential equal to one step on the first dial. Subdivision of succeeding dials may be carried out in the same way. In the case of the Feussner divider, Fig. 2, operation of any dial removes an increment of resistance from one side of the output terminal and introduces an equal amount of resistance into the other side. In both dividers the lowest dial can be in the form of a single-contact potential divider, a slide-wire frequently being used in this position.

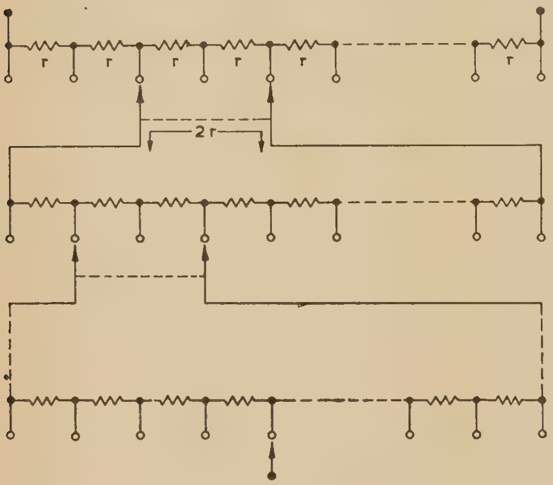


Fig. 1. Varley divider

Both these dividers have quite serious limitations when considerable subdivision is required or when the resistance of the divider must be low. A Feussner divider with N has $2(N - 1)$ switch contacts in series, all carrying the divider current. Little is to be gained in subdividing be the stage where the coil resistances are comparable wit variations in switch contact resistance. These variation a good quality copper-alloy switch, may amount to a milliohms, and in a silver-alloy switch to a few tenths milliohm.

The Varley divider is superior to the Feussner in s respects. Besides requiring fewer resistance coils an some designs, fewer contact studs, the influence of varia in contact resistance on the ratio is considerably less. maximum current in the switch contacts is only half the divider current and this is carried only by the contacts o first dial. The current is halved again at each lower di that the current in the contacts of the r'th dial is $1/2^r$ o total divider current. Instability of ratio due to chang contact resistance arises principally, therefore, in the dials, but the total error for all dials still remains s than in any one dial of the Feussner divider.

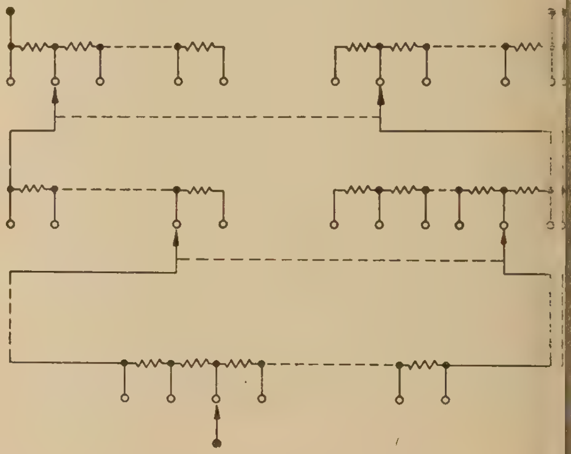


Fig. 2. Feussner divider

THE NEW DIVIDER

Consider now an extension of the Varley principle to c a more general class of divider network. Fig. 3 show first and second dials of a divider in which the coupled s arms s_1 and s_2 travel on independent sets of contact s The resistance per step of the first dial is denoted by r

---

* The term "Feussner" has now become accepted for a divider, the principle of which was, in fact, due to Rayleigh while the use of mechanically coupled dials was due to Weston (U.S. Patent No. 480 893, 1892).

tance of the section of the first dial bridged by s_1 and s_2 αr, and the effective resistance of the second dial sured between s_1 and s_2 by βr. If the potential ied to the second dial is equal to that of one step of first dial, the resistance of αr and βr in parallel must l r. Hence

$$\alpha\beta = \alpha + \beta \qquad (1)$$

$\alpha = \beta$, both α and β are equal to 2 and the upper ings in Fig. 3 become coincident with the lower ones are displaced two studs to the right. This is then

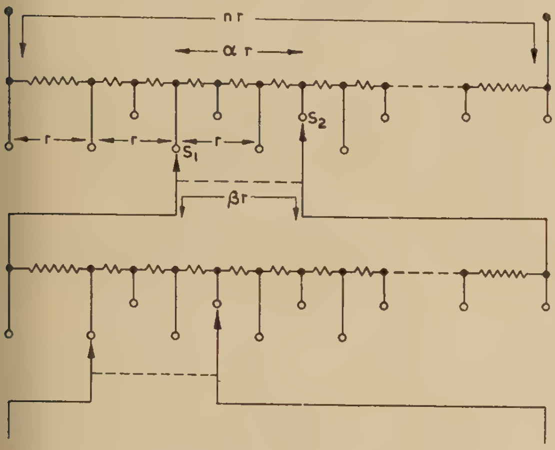


Fig. 3. General case of shunt circuit divider

Varley divider in which each dial bridges two coils of previous dial. If the total effective resistance of each is p times the resistance of one coil (p is 10 in decade em) the resistance of the first dial is pr, the second $2r$, third $4r/p$ and so on, decreasing by the factor $p/2$ for successive dial. Other simple variants of the Varley der are obtained by bridging three or more coils, e.g. when 3, $\beta = 3/2$ and when $\alpha = 4$, $\beta = 4/3$, etc. It is of rest that in the limiting case when $\alpha = \infty$ and $\beta = 1$, divider reduces to the Feussner circuit (Fig. 2) in which two sections of each dial are electrically separate and the t resistance of each dial is equal to that of one step of previous dial.

eturning to the arrangement of Fig. 3 in which s_1 and s_2 rate on independent sets of contact studs, a special case articular interest is that in which all dials have the same tance, i.e. $\beta = p$ and, from equation (1),

$$\alpha = \beta/(\beta - 1) = p/(p - 1) \qquad (2)$$

or a decade divider, $p = 10$, therefore $\alpha = 10/9$. For a der with 100-position dials, $p = 100$ and $\alpha = 100/99$.

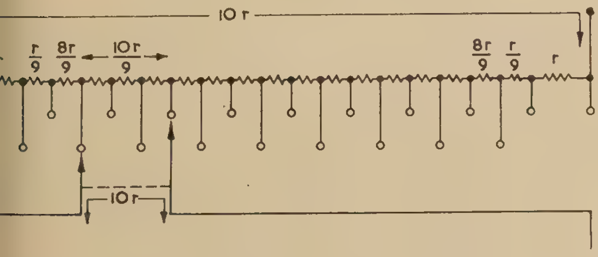


Fig. 4. Divider with constant dial resistance

Fig. 4 shows the arrangement of resistors and switches for a decade divider of this type. Only three values of resistance r, $r/9$ and $8r/9$ are needed, irrespective of the number of dials. The last dial takes the form of a simple divider with ten resistors each of value r. If desired, the number of resistance values can be reduced to two by making up the r's from pairs of $r/9$ and $8r/9$ resistors connected in series.

Besides simplicity of resistor units, the new divider has the important advantage of low current in the switch contacts. In the contacts of the main dial the current is only one-tenth of the total divider current and the switch current falls by a further factor of ten for each subsequent dial.

SWITCH CONTACT-RESISTANCE ERRORS

The various dividers described above may be compared, in regard to contact instability effects, in terms of a factor Σnm where n is the number of switch contacts in each dial and m is the ratio of the contact current to the total divider current, the summation being taken over the N dials of the divider. (In the dividers considered here the last dial makes no contribution to instability since it has no current-carrying contacts.) For the Feussner divider Σnm has the value $2(N-1)$, for the Varley divider $(1 + \frac{1}{2} + \frac{1}{4} + \ldots + 1/2^{N-1})$ and for the new divider $0{\cdot}2(1 + \frac{1}{10} + \frac{1}{100} + \ldots + 1/10^{N-1})$. In a four-dial divider, for example, these become respectively 6, 1·75 and 0·222. Hence the contact instability error in a divider of the new type with four decade dials is only about one-eighth of that in a Varley divider of the same resistance and one-twenty-seventh of that in a Feussner divider.

EXPERIMENTAL DIVIDER

The new divider has been constructed in the form of a 100 Ω, four-dial, low-inductance potential divider box using bifilar resistors of 10 Ω, 80/9 Ω and 10/9 Ω resistance. Having adjusted and intercompared all the resistors, those showing the minimum deviation from the mean were assigned to the top dial, the next most accurate to the second dial and so on. Selection of resistors in this way for the more critical dials is possible with the new divider since only a small proportion of the resistors of any one value must have the highest accuracy. Relatively large deviations from the mean are therefore allowable in the total group.

The experimental divider gave very satisfactory performance notwithstanding the use of radio-type wafer switches. The silver-plated contacts of these no doubt accounted in part for the good stability observed. On repeatedly resetting the switches at the zero dial settings the changes in the zero calibration in no case exceeded two parts in 10^7 of the input voltage, even after the instrument had been left undisturbed for several weeks. The actual zero error, with the wiring carried out as described below, was 12·4 in 10^6, but this was due almost entirely to the resistance of the thin brass contact clips of the switches. With more substantial switches, preferably of solid silver, it is anticipated that the zero error would be less than 1 in 10^6.

In order to reduce lead resistance effects to a minimum it is advisable to use the wiring arrangement of Fig. 5, at least in the case of a divider of low resistance. The leads a_1, a_2, a_3 and a_4 are regarded as part of the end resistors of the dials and these resistors are adjusted to value with the end leads attached, or with due allowance made for the lead resistance. The connexions to the end studs of the first and second dials are made by means of independent leads b_1, b_2, b_3 and b_4. The leads a_1, a_2, a_3 and a_4 cause no errors since they are included in the end resistors, whilst b_1, b_2 and the connexions to the first dial studs, c_1, c_2, etc., carry only one-tenth of the total divider current. Normally b_1 and b_2 are longer than c_1, c_2, etc., so that the error due to leads is a maximum at the settings 0 and 9 on the first dial. If r_l is the resistance of b_1 and the input terminal, and r_s the resistance of the switch between its junction with b_1 on one side and its junction with b_3 on the other side, the error in the first dial at the setting zero is 1 in $10R/(r_l + r_s)$, where R is the total divider resistance. The much smaller errors of the lower dials may be neglected. If $r_l + r_s$ does not exceed 1 mΩ, the zero error of the divider will not be greater than 1 in 10^4R, or 1 in a million for a 100 Ω divider.

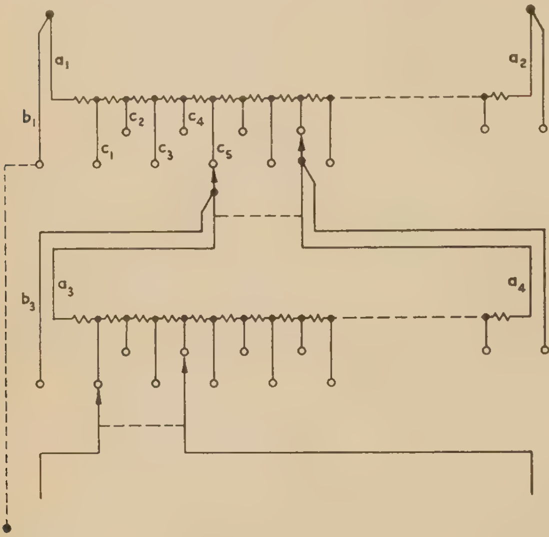


Fig. 5. Arrangement of leads for minimum errors

It is usual in a potential divider to provide a "low potential" output terminal in addition to the corresponding low potential input terminal and this is used when a four-terminal connexion is required. If this terminal is connected to the s end of the lead b_1 as shown by the broken lines in F the zero error with respect to this terminal will n influenced by the resistance of the lead b_1 or by the resis at the low potential current terminal.

The maximum resistance of the new divider, mea between the potential terminal and the input terminals the latter connected together, is higher than in the Var Feussner instruments and this may, in some applica partially offset its other advantages. This resistan always less than $NR/4$, where R is the input resistanc N the number of dials, and in the case of a decade d the resistance can be shown to be less than $(9N + 1)$ In applications where this resistance must be reduced minimum it would be advantageous to lower the dial tance after the second dial by the use of one or more mediate Varley decades. For example, a six-dial divider could have dial resistances of 100, 100, 20, 4, 4 Ω respectively, the second and third decades being V dials. The last three decades would then have a resis sufficiently low to allow the use of bare resistors mo directly by their leads on to the stems of the switch c studs.

ACKNOWLEDGEMENT

The author is indebted to Mr. H. C. Collins, of the Di of Electrotechnology, Commonwealth Scientific and I trial Research Organization, who carried out the mech design and the construction of the experimental divide

REFERENCES

(1) Varley, C. F. *Rep. Brit. Assoc., Notices and Abstr.*, (1866).

(2) Gall, D. C. *Direct and Alternating Current Pot meter Measurements*, p. 15 (London: Chapma Hall Ltd., 1938).

(3) Wolff, O. *Z. Instrumentenk.*, **21**, p. 227 (1901).

(4) Harris, F. K. *Electrical Measurements*, Chap (New York: John Wiley and Sons Inc., 1951).

Laboratory and workshop notes

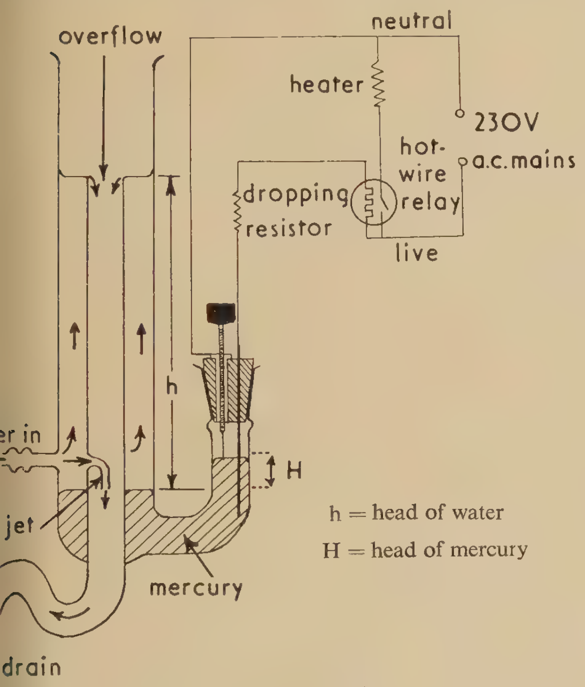
simple water failure guard for diffusion pumps and condensers

G. Houghton, M.Sc., Ph.D., A.R.C.S.,* Royal Technical College, Glasgow

[*Note first received* 9 *August, and in final form* 29 *November*, 1955]

imple guard was originally designed for the protection t water failure of a mass spectrometer constructed by thor. Failure of the water supply causes the mercury of the diffusion pump to distil into the vacuum system, ng in contamination, corrosion of vital parts and loss uum.

guard shown in the figure has many advantages: simple and easy to construct from readily available



h = head of water

H = head of mercury

Water failure guard

ials; there are no mechanical parts which can seize, de or fail by fatigue; an increase in water pressure or flow cannot cause a flood; the guard can be directly ated and used as a flowmeter.

e guard consists of two concentric glass tubes internally l at one end, with mercury filling part of the annular and a side tube. The water from the oil or mercury ion pump enters a side arm on the outer tube and rises eight h in the annular space. It is the hydrostatic head ter h which causes water to flow through a jet sealed he inside tube. The guard can be easily calibrated by iring the flow rates at different values of h and etching e on the outer tube. The length and diameter of the n be varied over a wide range to make flowmeters of ent capacities. The head h of water in the annular causes mercury to rise to a height H in the side tube $H = h/13{\cdot}6$. The mercury level in the side tube rises and falls as the water flow changes. By placing contacts in the mercury and connecting them to a relay, it is possible to cut off the diffusion pump heater when the water flow rate falls below a certain minimum value. If the water flow rate becomes too great, the excess water merely overflows into the inside tube and then to the drain. In actual practice the guard is usually operated with a small overflow, and the variable contact is adjusted to cut off the heater at the minimum water flow required for the diffusion pump.

Reference to the figure shows the neutral line of the a.c. mains directly connected to the water supply through the adjustable contact. For additional safety, the connexion of the a.c. neutral line to the water supply can be avoided by using the secondary of an isolating transformer to supply the potential to the heater of the hot-wire switch. When using an isolating transformer, the side of the secondary connected to the variable contact must be earthed.

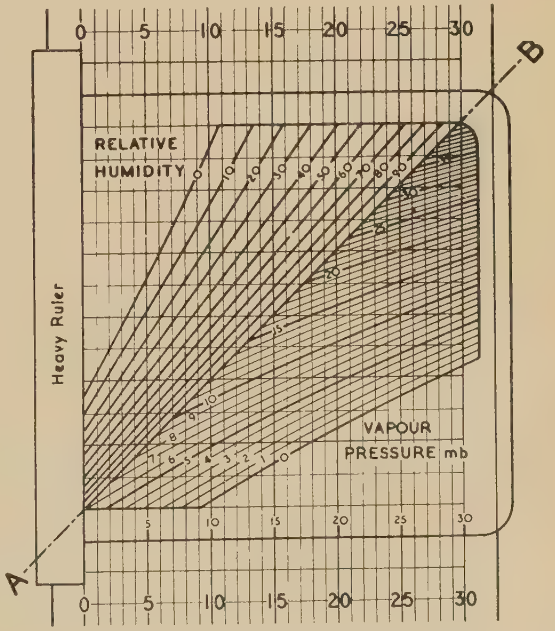
The direct evaluation of psychrometric data from dry- and wet-bulb recorders

By I. F. Long, Rothamsted Experimental Station, Harpenden, Herts.

[*Note received* 20 *May*, 1955]

In the analysis of records from self-recording dry- and wet-bulb psychrometers much time is spent in first reading the dry- and wet-bulb temperatures from the chart and then in computing the required function, such as vapour pressure or relative humidity, from the published psychrometric tables. Much of this tedious work may be avoided by the construction of a direct reading transparent scale of the function required in terms of the temperature data recorded.

As an example, a scale has been constructed for use with a 10 in. recorder chart, range 0–30° C, to give direct readings of vapour pressure and relative humidity (see the figure).



Scale for use with 10 in. recorder chart

---

* Now at Mellon Institute, Pittsburgh, Penn., U.S.A.

The grid, to be copied on the transparent sheet, is first plotted on a piece of the recorder chart, using the temperature scale of the chart as follows. First a reference line *AB* is drawn diagonally across the chart and at 45° to the base. For the vapour pressure scale this line is the *wet-bulb temperature* reference line, and it intersects all the vertical temperature lines of the recorder chart from 0–30° C. For any wet-bulb temperature recorded on the line there will be a corresponding dry-bulb temperature to its right: each such pair gives a unique value of vapour pressure, i.e. for any chosen value of vapour pressure it is possible to find a dry-bulb temperature to the right of the line *AB*. Based on Table 1, it is then possible to plot lines of equal vapour pressure on the chart, building up the family of curves shown.

Table 1. *Wet-bulb depression, for vapour pressure, against wet-bulb temperature*

Wet-bulb temperature (° C)		*Vapour pressure e, mb/Wet-bulb depression t − t′ (° C)*												
0	*e*	0	1	2	3	4	5	6	—	—	—	—	—	—
	t − t′	9·12	7·63	6·14	4·63	3·16	1·67	0·18	—	—	—	—	—	—
5	*e*	0	1	2	3	4	5	6	7	8	—	—	—	—
	t − t′	12·98	11·49	10·00	8·51	7·02	5·53	4·04	2·55	1·06	—	—	—	—
10	*e*	0	1	2	3	4	5	6	7	8	9	10	11	12
	t − t′	18·17	16·69	15·21	13·73	12·25	10·77	9·28	7·80	6·32	4·84	3·36	1·88	0·40
15	*e*	4	5	6	7	8	9	10	11	12	13	14	15	16
	t − t′	19·20	17·73	16·26	14·79	13·32	11·85	10·37	8·90	7·43	5·96	4·49	3·02	1·55
20	*e*	10	11	12	13	14	15	16	17	18	19	20	21	22
	t − t′	19·60	18·14	16·67	15·21	13·75	12·29	10·83	9·36	7·90	6·44	4·98	3·51	2·05
25	*e*	18	19	20	21	22	23	24	25	26	27	28	29	30
	t − t′	19·93	18·47	17·02	15·57	14·11	12·66	11·20	9·75	8·29	6·84	5·38	3·93	2·47
30	*e*	29	30	31	32	33	34	35	36	37	38	39	40	41
	t − t′	19·49	18·04	16·60	15·16	13·71	12·27	10·82	9·38	7·93	6·49	5·04	3·60	2·15

For the relative humidity scale to its left, the line *AB* is used as the *dry-bulb temperature* reference line. As before, for any dry-bulb temperature recorded on the line and for any chosen relative humidity, there will be a unique value of *wet-bulb* temperature to the left; so, based on Table 2, a family of curves of equal relative humidity can be built up.

Table 2. *Wet-bulb depression, for dry-bulb temperature, against relative humidity*

Relative humidity	*Dry-bulb temperature (° C)*						
	0	5	10	15	20	25	30
100	0·00	0·00	0·00	0·00	0·00	0·00	0·00
90	0·53	0·69	0·83	0·98	1·12	1·25	1·38
80	1·06	1·39	1·69	1·98	2·28	2·57	2·86
70	1·60	2·10	2·56	3·04	3·50	3·96	4·42
60	2·16	2·84	3·46	4·11	4·76	5·44	6·09
50	2·72	3·58	4·38	5·25	6·10	7·00	7·88
40	3·30	4·35	5·35	6·43	7·53	8·64	9·78
30	3·89	5·12	6·34	7·65	9·00	10·42	11·84
20	4·49	5·89	7·35	8·90	10·56	12·30	14·07
10	5·10	6·66	8·39	10·23	12·20	14·30	16·48
0	5·72	7·45	9·47	11·63	13·94	16·48	19·16

The grid now drawn, the recorder chart is placed face downwards and firmly fixed by strips of adhesive tape on to a piece of acrylic sheet, $\frac{1}{8}$ in. thick. Fixing by means of a paste is not advised, as the chart may be distorted by taking up moisture from the paste. The chart now fixed t transparent sheet is held to a light, the grid being ca transferred to the acrylic sheet by pricking throug recorder chart with a pin. The chart is then removed a required lines scored in with a sharp engineer's scribe. scored lines may be filled by using a wax "china-mar pencil, surplus wax being removed by polishing with a s cloth. The scales can best be labelled by using small n punches imprinted on the upper surface of the scale, bu has to be exercised not to split the acrylic sheeting pressing the punches.

To use the scale, a heavy straight edge is placed agai zero temperature line of the recorder chart. The trans scale can then be moved up and down the record, held against the rule. The reference line *AB* is placed so covers the wet-bulb temperature of the record, and the pressure is read direct from the scale at the position recorded dry-bulb temperature. The reference line i placed over the dry-bulb temperature, and the r humidity is read off the scale at the position of the we temperature.

Similar scales to the one described may be construc obtain the dew-point temperature, absolute humid vapour pressure deficit, according to the needs of indi workers. Tables 1 and 2 have been computed for us aspirated psychrometers, the psychrometric constant being 0·66 mb/° C.

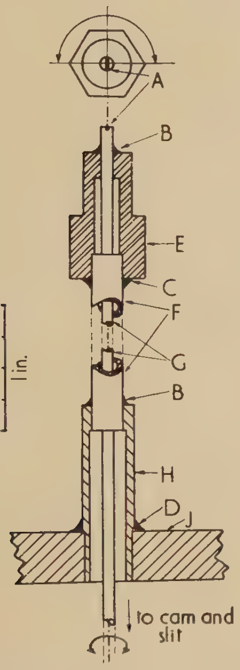
Transfer of movement into a vacuum by means of twis copper tube

By H. von Ubisch, Dr.techn. AB Atomenergi, St holm, Sweden

[*Note received 5 December*, 1955]

The usual way to introduce a movement directly i vacuum chamber is either by means of sliding gaskets as the Wilson seal, or by greased ground joints, or f hoses, bellows and diaphragms. For some purposes as the occasional adjustment of slit openings in mass sp meters, such devices are undesirable owing to their som poor vacuum qualities, complication, fragility, or su to pneumatic pressure and heat, besides the fact that ovements made possible are usually much larger than ed.

ch more satisfactory results can be obtained by using esign explained in the figure. The essential part is a copper tube of say ¼ in. diameter and some 2–3 in. , which can be twisted. The type of tube used for ds is suitable. A steel rod moving with ample clearance the tube transfers the rotation, and a cam on it actuates it. The rotation required is thus kept within ±90°, h such a tube will withstand occasional twists of one o revolutions. The author has not yet recorded a e of such a tube, having had two of them in use over ears. However, if the tube should fail, it could easily laced.



acuum seal incorporating a soft copper tube which is twisted plastically

direction mark on rod; *B*, silver solder (Easy Flow by nson, Matthey and Co. Ltd.); *C*, hard silver solder; *D*, ler or weld; *E*, brass nut; *F*, soft copper tube; *G*, steel rod; *H*, stainless steel fitting; *J*, stainless steel flange.

rods used should be of stainless steel in order to nt corrosion during acid cleaning of the assembly. The n top of the tube and rod may be turned simply by s of a wrench without undue care about keeping the straight, because the rod will take up this deformation. f support of the rod near its cam is required, however, allowance for some longitudinal movement must be . The elastic reaction of a soft copper tube when d presents no problem. Re-annealing of the tube s when the instrument is baked, and it could, of course, e carried out with a small torch. It may be mentioned he assembly is arranged on a fitting on the flange of ass spectrometer in such a way that it can be exchanged Kovar glass lead-ins.

application of this kind of seal under other severe or ular conditions suggests itself, such as for sealed-off ments, chemical systems, or in apparatus where nce against ionizing radiation is important.

A furnace over-temperature protection device

By R. J. Newman, A.M.I.E.E., Johnson, Matthey and Co., Ltd., Hatton Garden, London

[*Note received* 10 *May*, 1955]

The protection of high-temperature furnaces against excess temperature caused by faults in the control gear has always been difficult to achieve with a high degree of reliability. The fusible alloys can be reliable provided that they are inspected regularly and replaced if signs of deterioration are noticed. In cases where excess temperature would cause costly breakdown it has been customary to completely duplicate the control gear, using a second temperature controller which is left permanently set at the safety limit either for the furnace itself or for the process being carried out. It is thought that the apparatus to be described gives reliability at least equal to that of duplicated control, and at much lower cost.

The introduction by Standard Telephones and Cables Ltd. of a germanium junction photoelectric cell, type P.50.A, suggested that an optical system might be designed sufficiently small to be mounted within the casing of an ordinary edgewise-reading pyrometer indicating instrument.

The cell has a sensitivity of 30 mA/lm for tungsten light. The sensitive junction has, however, a very small area of about 0·06 × 0·02 in., so that in order to take advantage of the high sensitivity an efficient condenser system is needed to image a suitable glowing filament on the cell. It was decided at the outset that a miniature Edison screw bulb should be used, and the most suitable specimen readily obtainable is the 6·5 V, 0·3 A radio dial bulb which has been known by the author to give a life of 20 000 hours or more under normal running conditions. If the running voltage is reduced to about 5·0 V the expectation of life is increased by 20/30 times while the light output is reduced by 60/70%. This reduction in light output is not, however, suffered fully in the response from the photocell, which has a peak in the red region.

The cell may be taken for present purposes as a rectifier to which reverse voltage is applied. It breaks down on receiving light in such a manner as to give substantially constant current/light ratio, independent of voltage. It is therefore seen that the greatest power change may be obtained in an external load resistance by using the highest permissible cell voltage, stated by the makers to be 100 V. Since, however, complete tests on these cells have not yet been performed it was thought that, in view of the possible danger of breakdown when working near limit voltage, safety would be secured by using not more than 20 V. The maximum safe current for the cell is stated as 2·5 mA. It was found under test that best use of the available light was made by restricting the current to about 1·0 mA.

A relay suitable for operation under the above conditions is the Ericsson sensitive polarized type, which has two change-over contacts of iridium/platinum and works reliably on 0·7 mA in a 2000 Ω coil. Because the cell has a dark current which may be as high as 100 μA at the above voltage, a current is passed through the second relay winding in the reverse direction to ensure reliability of drop-out.

The amount of light required is about 0·03 lm, and the output from the under-run bulb approximately 1 lm total. It is therefore necessary to transfer at least 3% of the available light to the sensitive junction. To achieve a compact system with about 1 in. separation between filament and photoelectric cell, it was found necessary to use a pair of hyperboloidal lenses designed for the purpose by Combined

Optical Industries Ltd., whose type number for the component is S. 337.

These lenses are Perspex mouldings and appear to give good colour correction as there is no visible fringing. The components are arranged to give a 1 : 1 filament image on the cell, slightly defocused for ease of adjustment. The lens diameter is about $\frac{3}{8}$ in. but an annular plastic skirt is left in manufacture to provide an easy means of mounting. The working aperture is in the region of $f/1 \cdot 5$. The type of holder used for the bulb has a coil spring into which the bulb may be screwed and the filament alined parallel with the cell junction. Small adjustments of the light spot in the image plane are achieved by bending the bulb-holder bracket.

Fig. 1 shows the mechanical assembly as fitted to an instrument made by Industrial Pyrometer Ltd. The optical unit has been arranged to swing on a centre coaxial with the instrument pointer and is suspended from the removable cover. An auxiliary pointer attached to the assembly indicates the setting point on the temperature scale. With this arrangement adjustment of the setting point is only possible from behind the instrument panel but a suitable pair of gears can be mounted so that a panel knob may be used.

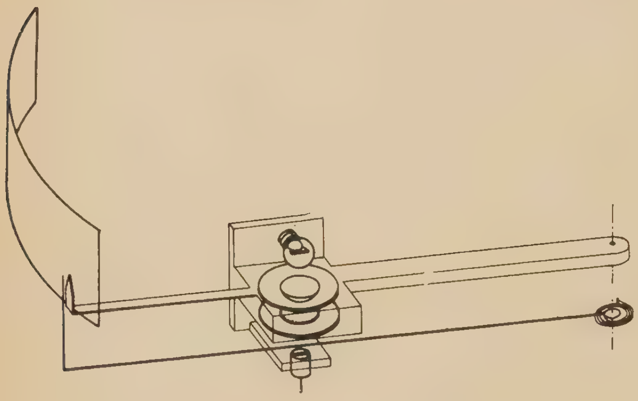


Fig. 1. Position of optical components

A mechanical stop has been fitted to prevent the pointer from passing beyond the position in which it obscures the light beam. A small paper flag has been attached to the pointer to ensure good obscuration but if the pointer can pass directly over the cell window this flag is unnecessary since the sensitive area, as previously mentioned, is only 0·02 in. wide, whereas the pointer is usually about 0·04 in. diameter, and can be made to interrupt most of the light, notwithstanding the fact that this is arriving along a cone of about 60° apex angle.

Fig. 2 shows one arrangement which has been used. The supplied voltage in this case is only 6 V. A broken thermocouple arrangement is included to give more than full-scale deflexion if the thermocouple circuit is opened. This will cause a small spurious deflexion which can be offset by means of the mechanical zero-adjustment of the pointer. A test switch has been introduced to densitize the instrument so that with the thermocouple disconnected, the instrument reading falls within its scale and allows adjustment of the optical system to be made.

With the arrangement shown it has been found that the mains voltage tolerance for satisfactory operation is about −20%, below which the relay will not reset after interruption of the light beam. It will be noted that a momentary failure of mains will shut down the furnace, which will not co
again when mains are restored.

As an alternative to its use for over-temperature prot
the device may be used to shut down a furnace when a c
temperature has been achieved.

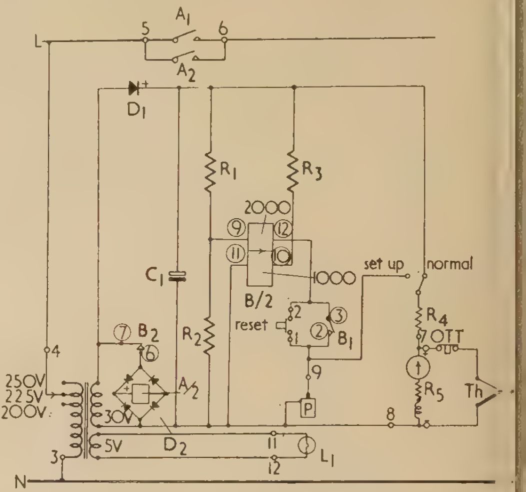


Fig. 2. Circuit of over-temperature protection devi

R_1–R_3 = 2·2 kΩ
R_4 = platinum/rhodium-platinum couple, 220 kΩ
R_5 = chromel/alumel couple, 100 kΩ
$B/2$ = Ericsson relay type N29827A1 (EET-LK)
C_1 = 25 μF, 50 V wor
P = P50A photocell
L_1 = 6·5 V, 0·3 A
D_1 = H18–3–1RW
D_2 = B18–2–1W
Th = thermocouple

By short-circuiting the reset button a simple
temperature controller is available, the switching over
which is in the region of 0·010 in. of pointer movemen
±1° C with a 6 in. instrument reading 0–1500° C.
hoped to arrange for narrow/band, on/off propor
control by the addition of a thermal cycler.

Acknowledgement is made to Johnson, Matthey an
Ltd. for permission to publish this note.

A beam splitter with illumination control

By P. M. Forsyth, B.Sc., A.R.C.S., and R. W. G. Hu
Ph.D., A.R.C.S., F.R.P.S., Kodak Ltd., Harr
Middlesex

[Note received 5 October, 1955]

In some instruments a piece of plane glass is mounte
light beam so that a part of the light is reflected on to a p
cell, which, by suitable electronic means, is then ma
regulate some parameter such as the voltage of a la
for instance, it is required to keep the intensity of th
beam constant.

In such a system it is desirable to have some means o
all adjustment. One method of doing this is to put n
density filters over the photocell. An alternative m
which avoids the use of neutral density filters and prov
continuous, rather than a step by step, adjustment, is
the piece of plane glass at such an angle that the light
is incident upon it at or near Brewster's angle, whi
ordinary glass is about 57°. This results in the reflecte
being largely plane polarized. Hence its intensity can b
conveniently varied by rotating a plane polarizer, suc
sheet of Polaroid polarizing filter, in front of the pho
This system has been found very useful in practice, the
of adjustment possible being over 100 : 1.

Correspondence

tomatic cathode-ray oscilloscope beam brightening device for transient recordings

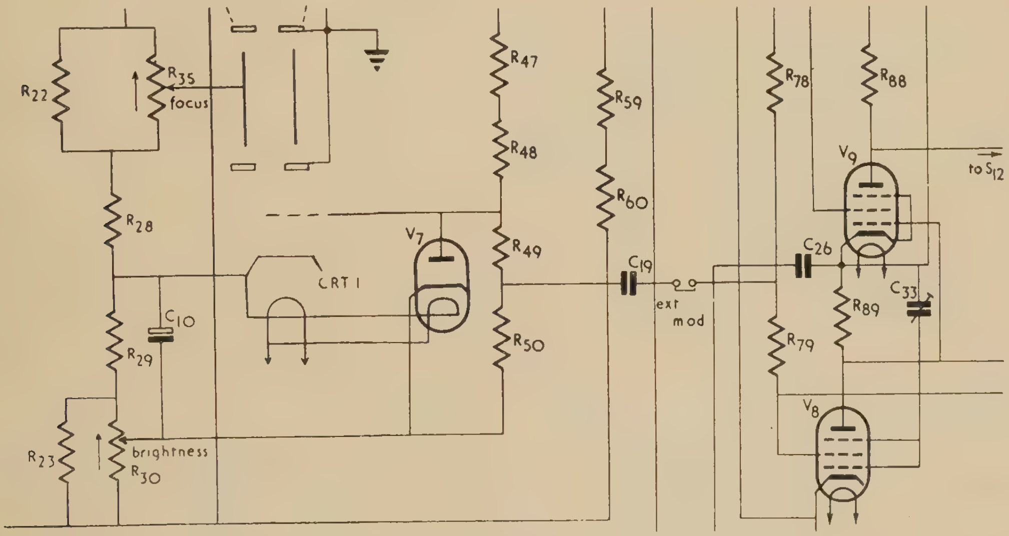
Vood's modification to the Cossor Oscillograph Model as described in his laboratory note on p. 401 of the er 1955 issue of this *Journal*, is both simple and effective e recording of transients of this type. I should like, 'er, to point out the effect of the modification on the mance of the instrument.

of the functions of the diode V_7, is to ensure that the f the cathode-ray tube is never positive with respect to thode, a condition which few tube manufacturers permit, due to the increase in cathode loading and quent reduction in tube life. It is possible to maintain rotection and obtain the desired performance if the le of diode V_7 is removed from resistor R_{50} and con- to the junction of R_{29}, R_{30}; resistor R_{47} must be nected as before.

ther function of diode V_7 is to provide d.c. restoration positive brightening pulses fed through capacitor C_{19} the "repetitive" time base is used. This restoration ke place on the tube grid if diode V_7 is removed. In form of this modification the "brightness" control is tive on the "triggered" ranges of the time base and 0-c/s intensity modulation is noticeable at slow speeds. effects, however, do not impair the performance of ery useful modification when transient waveforms are recorded.

O. H. Davie

pment Division,
Cossor Ltd.,
ury Grove,
n, N.5.



Part of time-base and associated circuit before modification

For transient operation the increased grid current is not of real significance because the grid of the cathode-ray tube is driven positive for the duration of the single sweep only.

Regarding the other points raised by Mr. Davie:

(*a*) D.C. restoration occurring in the cathode-ray tube grid instead of diode V_7: This is in fact so. However, the modification can be quickly performed and users can decide whether to make the modification permanent depending on the amount of transient work being carried out.

(*b*) Brightness control ineffective under triggered time base conditions: This means that the spot brightness is at maximum when the sweep is triggered regardless of the setting of the brightness control and is a desirable feature under some circumstances, i.e. fast writing speeds.

(*c*) 50 c/s intensity modulation at slow speed time base sweeps: This is evident as pointed out.

An improvement to the automatic beam brightening device has been developed since the submission of the laboratory note in November 1954. This improvement consists of inserting a 4·7 to 6·8 MΩ resistor (the actual value is not important) across the "ext mod" terminals in place of the existing shorting link. The effects of this resistor are to (*a*) reduce the amplitude of the brightening pulse and so prevent excessive cathode-ray tube grid current, (*b*) enable the brightness control to be used if required, and (*c*) eliminate 50 c/s intensity modulation.

This resistor will effect a complete cure for points (*b*) and (*c*) mentioned earlier and also limit the grid current to a safe figure which partly satisfies point (*a*). The resistor will also inevitably increase the brightening time by a further 2–3 μs.

J. Wood

Armament Research and
Development Establishment,
Ministry of Supply.

A monitored Geiger-counter X-ray powder diffractometer with automatic recording

The publication by Bond(1) and Benedict(2) of an account o their single-crystal automatic X-ray diffractometer prompts us to report another automatic instrument designed for highly accurate recording of *powder* diffraction patterns. "Step-scanning" of each diffraction line now becomes necessary, and, in common with the single-crystal instrument, techniques for rapid movement between lines and for "retracking" are used. A description of our equipment follows.

The apparatus will record a pattern on a chart in the usual way, but accurate determinations of the peak position and intensity of each diffraction line, as well as its centre of gravity and its integrated intensity, require more precise information than the chart can yield. Step-scanning is employed for this accurate work, and a direct plot of the profile of each line may be made from the record of such a scan if Geiger-counter dead-time losses are eliminated by incorporating the monitoring circuit of Eastabrook and Hughes.(3) This circuit also corrects the record for variations in the primary beam intensity, and reduces to about one-third the cosmic background recorded.

The fundamental scanning interval is 0·02° (2θ) and Dekatron counting tubes register the diffracted beam intensity. The recording is made by photographing the faces of these tubes, together with a register of the angle 2θ, at the end of each step. As in the apparatus of Bond and Benedict, the counter arm is arranged to move rapidly over the background region, and to traverse a line more slowly, but the mechanism of this process is rather different in our arrangement. The background is "stepped" without monitoring or recording in 0·2° steps; the counter remains stationary in each position only long enough to enable a counting-rate meter to reach a steady state. If the rate in a particular position is below a preset level, a further step of 0·2° is taken. If not, an electronic circuit operates a relay which reverses the stepping process so that twenty steps of 0·02° are taken without pause to bring the counter to the position before that in which the background was last sampled. A monitored 0·02° step-scan, with photographic registration, is then initiated and continues through the line until the counting rate falls below the preset level; a further ten steps of 0·02° are similarly recorded and then the background stepping recommences. From the photographic record of this process the line profile and the immediate background on either side may be plotted. The total number of counts made during the entire 0·02° step-scan is separately recorded on the film to assist in the rapid evaluation of the integrated intensity of the line. The whole process of scanning a diffraction pattern is automatic, and is controlled by a sequential circuit which uses Post Office relays. Facilities for continuous step-scanning as well as manual recording are also available.

The camera, which is of special design, can store 20
35 mm film which is led under a shutter into a ca
When the camera is placed in the main equipment ra
"leader" of film is automatically wound on, and the c
is locked in the rack. When a record is complete
length of film between the shutter and the cassette,
carries the latter part of the record, is automatically
into the cassette before the camera can be withdra
removal of the cassette and processing of the record. D
for indicating the number of exposures made, and the
of film remaining in the store, are also incorporate
entire recording process ceases if the store of film be
exhausted.

The apparatus has been developed with the aid of a
from the crystallographic data fund held in trust b
Institute of Physics. It will be on show at The P
Society's exhibition this year, and a full description of
be published in due course.

Viriamu Jones Laboratory, J. W. HUG
University College, Cardiff. E. R. PIKE

REFERENCES

(1) BOND, W. L. *Acta Cryst.*, **8**, p. 741 (1956).
(2) BENEDICT, T. S. *Acta Cryst.*, **8**, p. 747 (1956).
(3) EASTABROOK, J. N., and HUGHES, J. W. *J. Sci. In*
30, p. 317 (1953).

Calibration of a stroboscopic light

In a previous issue of this *Journal* Lemlich* descr
method of calibrating a stroboscopic light over its
range by utilizing a piece of machinery rotating at a
constant speed. It may be of interest to point out that
forks also provide a simple and accurate means of calib
stroboscopic lights. Sets of tuning forks are not ord
available in machine shops, but are standard equipm
physical and physicochemical laboratories. The
regularly employed in this laboratory for the calibrat
stroboscopic lights, which are in turn used for mea
the rotation speeds of air-driven and electrically
centrifuges.

Eastern Utilization Research Branch T. F. FORD
Agricultural Research Service, T. G. ALEXA
United States Department of
Agriculture,
Washington, D.C., U.S.A.

---

* LEMLICH, R. *J. Sci. Instrum.*, **31**, p. 191 (1954).

New books

e-edge bearings. By P. J. GEARY. (Chislehurst, Kent: British Scientific Instrument Research Association, 1956.) Pp. viii + 61. Price 10*s*. 6*d*.

booklet is the second in B.S.I.R.A.'s bibliographical eys, and it is as welcome as its predecessor. In his fore- l, Mr. A. J. Philpott points out that the survey has shown most of the design and investigation of knife-edge ings has hitherto been empirical; the survey therefore s a good starting-point for more exact investigations, les summarizing, with of course adequate references and acts, what is already known of the field. The compiler nelpfully indicated where the originals of his references be found.

is refreshing to find from the bibliography that the tzian stresses" that enter into such problems as the ig of wheels on a railway, and into the flattening of a -edge under load, were yet another interest of the rated discoverer of radio waves and the photoelectric t.

R. V. JONES

um valves in pulse technique. By P. A. NEETESON. (Einthoven: Phillips Technical Library; London: Cleaver Hume Press Ltd., 1955.) Pp. viii + 170. Price 27*s*.

e past two decades the development of pulse techniques ad repercussions in the field of electronics of which we s yet but dimly aware. Radar and the digital computer wo of the more spectacular products of the exploitation lse circuits.

e extension of circuit analysis to include valves used r pulse conditions has lagged behind the applications as presented serious difficulties. The book under review voted to the analysis of some of the more important circuits and the approach has a much wider field of cation.

the first six chapters the theory of valves used as switches veloped and the elements of operational calculus intro- d. The remainder of the book contains detailed analysis variety of multivibrator circuits, showing the significance e various valve parameters.

e theoretical work is supported by experimental results clarified by numerous diagrams and oscillograms. The criticism of the book lies in its limitation to thermionic s. The similarities between these valves used as switches cold-cathode valves are so strong that a comparison of relative merits would have been most helpful. How- the book is well worth reading by all who are concerned the applications of the multivibrator.

F. MORAN

Neolaborograph: theory and practice. (Laboratory Vhite Books No. 9.) By I. T. RADA. (Budapest: Elektroimpex, 1956.) Pp. 103.

title of this book is misleading. It contains no theory t for an inadequate and often inaccurate introductory n on the significance and principles of measurement of echanical properties of flour doughs and some equations ibing the working of a complicated machine. Space not permit detailed criticism, except to point out that atement that "no simple and rapid test method has been ed so far" would be widely disputed.

e rest of the book consists of a detailed account of the working of the "Neolaborograph," a machine which mixes a dough, forms a test-piece and finally subjects this to a highly complex tensile loading. A load-deformation curve is plotted and the rupture-values obtained. In spite of numerous lettered photographs and diagrams, your reviewer finds it impossible to follow in detail the working of this highly complicated machine. It is also a pity that the translation of the instructions is not better.

This is not to say that the test may not give useful empirical information about flour quality, if anyone can be found to master the highly complex technique, corrections, nomographs, etc.!

G. W. SCOTT BLAIR

General aspects of radio interference. British Standard Code of Practice CP 1006: 1955 (London: British Standards Institution). Price 10*s*.

The population of this country regards radio and television as normal, almost essential, services. Interference to them is a national problem. More restricted, but intrinsically more important, are the safety services such as navigational aids for ships and aircraft. The Wireless Telegraphy Act of 1949 gives the Postmaster General powers to make regulations which will restrict the use of interfering apparatus. He has made regulations under this act with respect to ignition systems, refrigerators and small motors. To avoid hardship and ensure practicability in a subject about which the average person knows very little, statutory regulations must be hedged about with safeguards. Furthermore this country is lucky in enjoying high broadcast field-strengths which reduce the severity of interference. Thus progress in reducing interference requires a great background of technical information and advice directed towards those capable of using it. Part is supplied by publications and the reports of bodies such as the G.P.O., B.B.C. and E.R.A. Part is supplied by British Standards which show how to measure interference and the limits to which it should be abated in various instances. In addition to the foregoing, there is need to explain as simply but as comprehensively as possible how interference can be reduced. This is appropriate not to regulations or to standards or to specialized technical reports but to a code of practice. The present code of practice covers the ordinary wavelengths for sound broadcasting and the television wavelengths 41 Mc/s to 68 Mc/s in Band I. Experience is inadequate in Bands II and III, consideration of which is deferred to a later revision. The code covers most types of interfering appliance, but excludes ignition systems and apparatus which normally and essentially generate radio frequency energy, such as transmitters, receivers, industrial, scientific and medical equipment using radio frequencies.

The code briefly describes how interference is generated and transmitted and how different kinds can be recognized. It deals with action which can be taken at the receiving site but most of the code is devoted to the different ways in which the interference may be abated at the source. The code draws attention to the need for the proper design and maintenance of electrical installations. A surprisingly large number of complaints arise from inadequate maintenance. The sharing of the responsibility for interference abatement between the listener or viewer and the user of appliances is emphasized. The code is well written and attractively illustrated. It is timely and valuable: it ought to be widely disseminated.

S. WHITEHEAD

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or in products. The Institute of Physics assumes no responsibility for the statements given below: information for these ha taken from literature supplied.

Electronic temperature controller. Fielden Electronics Ltd., Paston Road, Wythenshawe, Manchester.

This relatively simple and compact controller is based on the use of a resistance thermometer in an a.c. bridge. The bridge output is amplified and controls an on-off relay. Simple on-off control of this type is suitable when the thermal lag of the controlled system is small. The instrument, which is contained in a cast aluminium case, $6\frac{3}{4} \times 7\frac{3}{4} \times 4\frac{1}{2}$ in., is capable of responding to temperature variations of 0·1° C and of controlling, through the relay contacts, currents of 5 A at 250 V a.c. It is available in standard ranges between the limits −200° C and +500° C.

Low-frequency waveform generator. Servomex Controls Ltd., Crowborough Hill, Jarvis Brook, Sussex.

The LF51 generator provides a very wide variety of waveforms covering periods from 1 ms to 1000 s. The four main available waveforms are square waves, triangular waves, sawtooth waves and pulses, but by a separate selector switch each type of wave can be used in three ways.

(*a*) Continuous repetition.

(*b*) Single sweep, either from the positive limit to the negative or *vice versa*. Thus, square wave, single sweep gives a true step voltage. Triangular wave, single sweep gives a linear change from one voltage to another, with the change completed in any selected time from 1 ms to 1000 s.

(*c*) Double sweep or one complete cycle.

Thus, square wave, double sweep gives one flat-topped pulse.

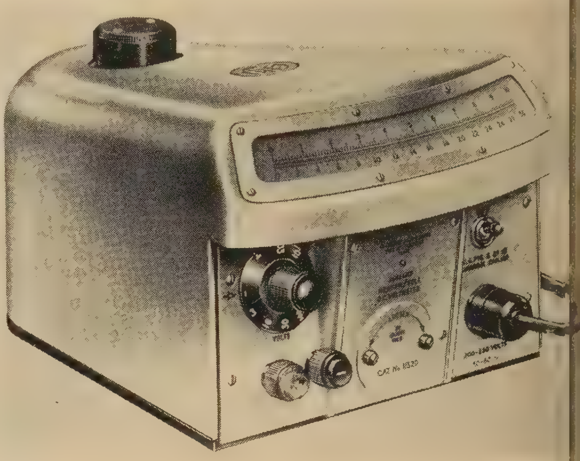
The range of times is covered in six decades. An absolute accuracy of 2% of the indication is claimed, but it is stated that the incremental accuracy and re-setting accuracy are much better.

The peak-to-peak output voltage is available in six ranges of 1·5, 15, 150 mV, 1·5, 15 and 150 V. Each range is available on a calibrated dial on a continuous potentiometer, and the absolute accuracy is stated to be 3% of the full scale. A particular feature of the instrument is the method of controlling the amplitude, which causes the upper and lower limits of the excursion to expand symmetrically about the selected "centre voltage," which can be adjusted over the range ±75 V to earth. This voltage is monitored by a centre-zero voltmeter. It sets the d.c. level for symmetrical waves, but on pulse output the top and bottom of the pulses are equally displaced from the centre voltage and thus the amplitude control causes a change of d.c. level. Thus, the *limits* of the excursion are fixed, regardless of the waveform selected. The short-term stability of output voltage is claimed to be about 1 mV in general use. On the two lowest ranges, the variable centre voltage facility is cut out and the output is taken from a 100 Ω potentiometer earthed at the bottom end. Thus the drift is reduced at the expense of having to work symmetrically about earth potential. Mains voltage changes of ±7% cause a drift of output level of 5 mV on the four upper ranges, together with a change in peak-to-peak output of 0·2%.

The output impedance is 100 Ω on the two lowest ranges and from 10 to 30 Ω on the others. The final velocity on a linear sweep is less than the initial velocity by 1%; the rise time (10–90%) on square waves and pulses is about 5 μs.

D.C. voltmeter of high resistance. W. G. Pye and Co. Granta Works, Cambridge.

The Scalamp built-in mirror galvanometer with suspension, moving coil has been adapted as a direct-re voltmeter having a resistance of 1 MΩ/V on all r This compares favourably with many electronic voltm and is claimed to have the advantage of cheapnes relative freedom from drift. The range multiplier and resistors are enclosed in a sealed box within the instr which is fitted with a desiccator to ensure stability resistors. An overall accuracy of 1% of the full-sc claimed on each of the ranges 10, 30, 100, 300 mV, 1, 3, 100 and 300 V. The instrument is critically damped response time of 2 s.



High-resistance, d.c. voltmeter using galvanometer mov

Oscillator with sine- and square-wave output. W Electronics Ltd., Shepperton, Middlesex.

This instrument is described by the makers as a c oscillator. In fact, the frequency range covered is 10 100 kc/s by means of a dial scaled 10 to 100 in conju with a multiplier range switch with settings ×1, ×10, and ×1000. The instrument employs a Wien resistance-capacity oscillator with thermistor stabili The frequency accuracy is given as $1\frac{1}{2}$%, with a stabi 0·02% due to normal ambient temperature changes. voltage changes of 10% cause a 1% change of freq When arranged to give a sine wave, the output volt 10 V peak and is fed through an attenuator with st ÷1, ÷10, ÷100 and ÷1000. The harmonic cont stated to be less than 1% and the hum less than 0·1%. arranged to give a square-wave output, the rise time is to be 0·3 μs at 100 kc/s, and the maximum drop at 10 c/s.

Electronic temperature controller. Foster Instrumen Ltd., Letchworth, Herts.

The control mechanism of this device is a pointe pivoted, moving-coil milliammeter which can be u conjunction with a resistance, thermocouple or rad ometer. The pointer of the meter has a light metallic ttached to it. As the position of the pointer approaches esired temperature reading, the vane passes between xed metallic plates mounted on an adjustable arm, this set to the required temperature. The movable vane he two fixed plates form a capacitor whose value ses from minimum to maximum as the pointer aches the control setting. This capacitor forms part oscillatory circuit that is connected to a trigger circuit olling a relay which in turn is connected to a final relay o control the energy input to the plant. It is claimed his system gives a control differential of 0·15% of ale reading and a control point stability of 0·1% for a ion of 10% in mains voltage.

ture relay. Ericsson Telephones Ltd., Beeston, ottingham.

ype 2 miniature relay of medium sensitivity is mounted sealed metal container. The balanced movement is tly constructed and is claimed to withstand accelera- up to 75 *g*. The size and shape of the relay make able for use in equipment using miniature valves. It ended for chassis mounting, the cylindrical metal can ining the movement being 1 in. in diameter and pro- g about 2 in. in front of the chassis; the leads project behind the chassis. The normal relay carries up to four eover platinum contacts rated at 35 W; a heavy duty n is fitted with up to two make and two break contacts at 200 W. The coils, which are rated at from 0·6 to ', are available for operation at voltages from 1·3 V.

susceptibility meter. Mount Sopris Instrument Corporation, 1320 Pearl St., Boulder, Colorado, U.S.A.

nodel MS-160 susceptibility meter is of the induction nd is intended for *in situ* measurement of rock suscepti- or for the laboratory measurement of crushed rock es. The instrument contains a stable 1 kc/s oscillator g a power amplifier with low harmonic output which es a modified mutual inductance bridge. The three nsing element is included in one arm of the bridge. If oil assembly is placed upon a rock outcrop, the magnetic tibility of the rock produces a change in the self and l inductance relationships existing within the coil bly. The bridge is balanced by means of a 10 turn tiometer and susceptibility is found from a calibration which relates susceptibility directly to the change in g of the potentiometer dial. A parallel-T feedback, w-band amplifier is used with headphones as a null or for the bridge. The narrow-band amplification ates the harmonic output from the bridge and in on reduces power line or other stray electrical pick-up to igible value. The non-inductive frequency-determining nts of the oscillator and narrow-band amplifier ensure ty with respect to temperature and eliminate the ility of stray coupling between oscillator and detector. ypes of coil are supplied with the instrument. For field coil assembly 25 in. in diameter is used. This, when on the surface of the rock, yields a measurement of the tibility of a hemisphere of 50 cm radius. With these a displacement of 0·5 cm with respect to the rock e introduces an error of only 0·3% in the susceptibility rement. For laboratory use, a set of coils is supplied takes core samples or test tubes containing rock chips. nge of the instrument is from 5×10^{-5} to 10^{-1} c.g.s. unit. The bridge itself is claimed to have an accuracy corresponding to 3×10^{-6} c.g.s. unit, and the precision of an *in situ* measurement is given as 2×10^{-5} c.g.s. unit or 3% whichever is the greater.

Moisture meter. Shaw Electronics, 31 Market Street, Bradford.

A moisture meter has been designed which measures dielectric constants at a frequency of 150 Mc/s. Its 5 in. meter dial indicates moisture readings from 0–100%. It is stabilized for operation from 200–250 V, 50 c/s, mains supplies. The sample weight is from 10–50 g and the total weight of the meter is 10 lb.

Miniature dry cells. Burgess Battery Co., Freeport, Illinois, U.S.A.

A great reduction in the size of the Leclanché dry cell is made possible by a wafer type of construction. The cell consists of a sandwich of manganese dioxide mixture between flat disks of zinc and carbon. The whole sandwich is wrapped in a thin plastic film and heat-sealed. Connexion between cells is made by an electrical conducting silver wax. A dab of silver wax on the positive and negative sides of the cell permits the cells to be connected in series by being stacked in a column. The whole cell stack is wrapped in a polyester sheet, heat-sealed and compressed into an aluminium or steel sheath. The general method of construction and size of the cells is shown in the figure. The battery on the right of the figure has a nominal e.m.f. of 22·5 V and is intended for pocket radios, hearing aids, Geiger counters and similar devices. The individual cells are manufactured in five sizes from $\frac{3}{8}$ to $1\frac{1}{4}$ in. cross-section. It is claimed that the method of construction enables about 30% more active material to be packed into a given volume as compared with the conventional construction.

Miniature Leclanché dry cells

Manufacturers' publications

Copies of the publications mentioned in this Section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

High temperature alloys. Henry Wiggin and Co. Ltd., Birmingham 16. Design data on the entire range of Nimonic alloys, including preliminary details of the recently introduced creep-resisting material Nimonic 100, are contained in the latest edition of *The Nimonic Alloys.* Extensive revisions have been made in this booklet in the light of creep and fatigue test results obtained since the earlier edition was published. For example, 10 000 hour creep data for Nimonic 90 and 95 are included and the fatigue properties of Nimonic 80A at 700° C and 750° C are indicated by means of Gerber diagrams. Other information given on the Nimonic alloys includes the specified compositions, hardness ranges, physical properties, recommended heat treatments, short-time high-temperature tensile properties and results of torsion tests.

Lubrication using molybdenum disulphide. Rocol Limited, Ibex House, London, E.C.3. Several publications give details of a range of lubricants called "molybdenised lubricants." These consist of combinations of molybdenum disulphide with oils, greases, water, soaps, solvents, silicones, diesters and other fluids. It is claimed that molybdenum disulphide is resistant to heat, oxidation, light and all common solvents and chemicals. It has a low coefficient of friction, resists extreme pressures, shears readily and bonds to ordinary engineering metals and plastics.

Electronic devices. The General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2. A forty-page publication provides a brief guide to the range of electronic devices produced by this firm. The headings used are: cathode-ray tubes, special purpose valves, semi-conductor devices, Geiger–Müller tubes, stabilizing devices, photoelectric cells and devices. A table of the nearest G.E.C. equivalents to the C.V. types is included.

Noble metal thermocouples. Johnson, Matthey and Co., Ltd., 73–83 Hatton Garden, London, E.C.1. A thirty-six page booklet entitled *Noble metal thermocouples*, by H. E. Bennett, briefly surveys methods of high-temperature measurement and the development of the thermocouple. It also deals with applications of the platinum metal thermocouple, with particular reference to its use in the steel industry, and with methods of calibration. A further section covers the properties of the platinum-group metals and their alloys in relation to the problems of temperature measurement; in addition, information is given on the principal causes of deterioration of thermocouples under the heads: effect of strain, effect of prolonged heating at high temperatures and contamination. A bibliography and index are included.

Waveguide components. Hilger and Watts Ltd., Hilger Division, 98 St. Pancras Way, Camden Road, London, N.W.1. Literature is available which describes a range of waveguide components for the 8 to 10 mm waveband—the "Q band." The components are based on standard size WG22 with internal dimensions of 0·280 by 0·1 They include wavemeters and reference cavities, standing- indicators, attenuators, directional couplers, wave switches, isolators, crystal holders, and thermistor moun addition to lengths of drawn or precision electroformed They are normally fitted with U.K. standard pressu screwed-ring connectors with plain flanges, but choke fl or U.S.-type flanges are available as alternatives.

Optical glass. Chance Brothers Limited, Glass W Smethwick 40, Birmingham. Catalogue O.S.16 co comprehensive specifications of various types of optical The new types of glass included in this catalogue are b crown, barium flint, extra dense flint, double extra flint, borate flint, special barium crown, special barium

Microwave equipment. Elliott Brothers (London) Elstree Way, Borehamwood, Hertfordshire. Further have been issued which give details of microwave equi for the 3·2 cm waveband. The equipment includes a cision, standing-wave indicator, a rotary attenuator a monitor diode. A leaflet describing a monitor diode f 10 cm waveband is also available.

Errata

There are two small errors in the figures used to il "A fast multiple coincidence circuit" by B. Collinge, Merrison and D. Eccleshall, published in the Februa issue of this *Journal.*

Fig. 2. The junction of R_{14} and R_{15} should be joine the junction of R_{16} and C_4

Fig. 4. The resistor connected to the -200 V should be marked 10 kΩ

British Journal of Applied Physic

Contents of the May issue

SPECIAL ARTICLE

The physical meaning of indentation and scratch hardness. By D. Tab

ORIGINAL CONTRIBUTIONS

A re-determination of the equal-loudness relations for pure tones. B Robinson and R. S. Dadson.

The spectral quantum- and energy-efficiency of calcium tungstate X-ray i ing screens. By R. H. Herz.

The production of transparent profiles of dust particles as an aid to aut particle counting. By R. J. Hamilton and B. A. Phelps.

Measurement of the half-life of radon with a Curie-type ionization c By P. C. Marin.

A photoelastic method of two-dimensional separation of stresses along symmetry by using the isochromatic fringes only. By S. P. Christod

NEW BOOKS

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the princi construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Sq London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparati contributions.* (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon appli from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Lon E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received withi days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of ad or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payab advance. Single parts, so far as available, may be purchased at 10*s*. each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institu Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

A proportional counter tube for X-ray diffraction analysis

By A. R. B. Skertchly, B.Sc., University of Leeds

[*Paper received* 17 *January*, 1956]

An argon-filled, ethyl alcohol quenched counter utilizing a diagonal radiation absorption path is described. The quantum efficiency is 67% when detecting CuKα quanta. When it is used in conjunction with a single-channel pulse amplitude analyser operating with a bandwidth of 3·6 V centred at 30 V its overall efficiency is 46%. Little distortion is introduced into the pulse height distribution curve owing to the incomplete dissipation of the energy of the photoelectrons, and the required low capacitance for high signal-to-noise ratios at low operating potentials is preserved.

specific design of proportional counters for use as X-ray nta detectors has been neglected; consequently, optimum formance efficiency is not obtainable with existing types.

y the simple expedient of designing a proportional nter with diagonally opposed windows, and introducing X-ray beam at a small angle to the window, greatly eased quantum absorption efficiency is readily obtained other desirable attributes, such as low capacitance and rt resolving times, are not impaired.

schematic drawing of the tube and its components is wn in Fig. 1. Windows are placed at a sufficient distance n the ends to ensure a uniform field where the beam ers.

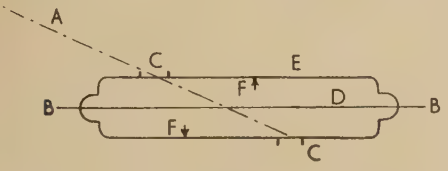


Fig. 1. Proportional counter tube

, incident X-radiation; *B*, tungsten anode wire (0·1 mm iameter); *C*, bubble glass entrance and exit windows ·2 mm); *D*, counter gas filling (97·5% argon, 2·5% ethyl lcohol); *E*, glass tubing (2·0 cm diameter); *F*, aquadag cathode surface.

he main absorption gas is argon (97·5%) and the polymic quenching agent is ethyl alcohol (2·5%), to a total ssure equal to 76 cm of mercury. This combination has n shown to be linear in energy response and extremely le.(1)

WALL EFFECT

Vith such a small angle of incidence it might be expected t the "wall effect" (incomplete dissipation of the energy a photoelectron before colliding with the wall) would be reciable. It is shown below simply that this is reduced l below that to be expected in many proportional counters. t is assumed that:(2)

i) all photoelectrons are liberated perpendicular to the beam;

i) an approximate mean range for the photoelectrons is given by,

$$r = V^2/b$$

where b = a proportionality constant (for argon at 76 cm $b = 6 \cdot 1 \times 10^2$); V = energy in kilovolts (for CuKα = 1·54 Å the maximum energy of a photoelectron is 5·1 kV); and $r = 0 \cdot 041$ cm.

Fig. 2 shows the angular and distance nomenclature adopted. The "wall effect" is obviously only of importance near the entrance window as it is here that maximal absorption occurs.

$$\theta = \arccos\left[\frac{D^2 - 2bD + r^2}{2r(D-b)}\right].$$

Within the range $\theta = \arccos(r/2b)$ to $\theta = 0$, x ranges from 0 to $D = x \tan \psi = kx$ (say).

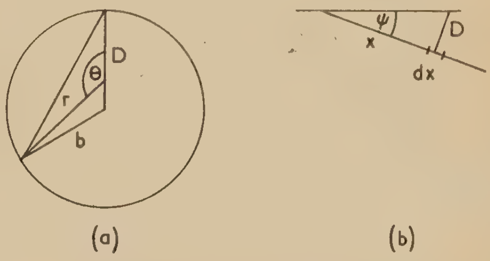


Fig. 2. Counter cross-sections

(*a*) Section perpendicular to the counter's longitudinal axis. *D*, distance from wall of X-ray path; *r*, range of photoelectrons; *b*, counter radius; θ, angle between the vertical and extreme range vector.

(*b*) Longitudinal section in the plane of the incident beam and counter axis. *x*, distance of absorption path into the counter; ψ, angle between horizontal and incident beam.

At a particular distance x in the region dx there are dA_1 photoelectrons liberated

$$dA_1 = I_0 \exp(-\tau x)\,\tau\,dx$$

(τ = linear absorption coefficient). Of these the fraction θ/π are within wall range.

$$\text{i.e.}\quad dA_2 = I_0 \exp(-\tau x)\,\tau\,\frac{\arccos}{\pi}\left[\frac{K^2x^2 - 2bKx + r^2}{2(Kx-b)}\right]dx$$

so that the total fraction within wall range

$$A = \int \frac{dA_2}{I_0} = \int_0^{r/\tan\psi} \exp(-\tau x)\,\tau\,\frac{\arccos}{\pi}\left[\frac{K^2x^2 - 2bKx + r^2}{2(Kx-b)}\right]dx$$

To obviate a series integration, a high estimate may be obtained by the simplification

$$A = I_0 \int_0^{r/\tan\psi} \exp(-\tau x)\,\tau\,dx$$

where $r = 0{\cdot}041$ cm, $\tan\psi = 0{\cdot}1763$, $\tau = 0{\cdot}202$, and $A = 0{\cdot}05\,I_0$. At $x = 0$, θ is given by arcos $(r/2b) \simeq 80°$ so that $A = 0{\cdot}025\,I_0$.

It is evident, then, that approximately 2% of the quanta will not have expended all their energy before reaching the wall and these will contribute to the low energy tail, and introduce a small measure of asymmetry.

The energy distribution curve is plotted in Fig. 3 for the typical case of CuKα. It is seen that the argon Kα fluorescence is well evident, and that a very small amount of additional asymmetry is introduced by the "wall effect" already mentioned. The smallness of the effect appears to justify the approximate analysis given.

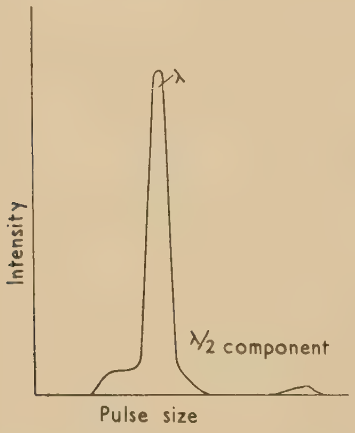


Fig. 3. Typical pulse height (energy) distribution curve for the case of copper radiation (30 kV peak, nickel filter) showing both argon Kα fluorescence and a λ/2 component. The marked asymmetry of the harmonic component indicates that the "wall effect" is becoming appreciable under tnese design conditions at this energy

The counter's quantum efficiency is effected by an almost negligible amount, however, and this is of vital importance in X-ray diffraction analyses where the beam intensities are low, such as is the case with biological and proteinous materials.

FURTHER CHARACTERISTICS

The quantum efficiency, assuming a one-to-one correspondence between an absorption event and a counting event, is 0·67. That is, 67% of the radiation impinging of the counter contributes to the signal.

Of importance is the low electrical capacitance ($1{\cdot}47 \times 10^{-12}$ F) which results in the following values of the signal/noise ratio(3) being obtainable at a gas amplific of 1000, for a total input capacitance of 10^{-11} F.

signal/peak noise = 20
signal/r.m.s. noise = 120

The peak noise value being calculated on the basis c noise peak equalling or exceeding the signal pulse once 600 seconds. Also notable is the improvement of sign background ratio (by a factor greater than 2) over e tubes.

OVERALL EFFICIENCY IN CONJUNCTION WI A PULSE AMPLITUDE ANALYSER

If a single-channel pulse amplitude selector is us order to partially "monochromate" the beam, then counter efficiency must be modified by the pass band o amplitude analyser. Thus, assuming a Gaussian freq distribution with a coefficient of variation of 6·7%(4) f energy distribution of CuKα quanta, we find that for a l width of 3·6 V centred around 30 V, 68·3% of the poten available quanta are passed. This results in an o efficiency of 46%.

ASSEMBLY

The bubble glass windows were blown into the glass tu and the cathode surface formed by an inner coati Aquadag (colloidal graphite in water). After fitting electrodes, and flushing and filling, the tube was seale counter was specially constructed by Twentieth C Electronics Ltd.

CONCLUSION

Similar design criteria can obviously be applied to cou suitable for radiation other than that centred aroun CuKα region and it seems evident that more efficiency satisfaction in performance can be achieved by deliberat careful design.

ACKNOWLEDGEMENTS

My thanks are due to Mr. H. J. Woods and Dr. J. Sik for helpful discussions and to the International Secretariat for a research fellowship which has enable work to be carried out.

REFERENCES

(1) Parry, J. K., Rathgeber, H. D., and Rouse, J. L. *Phys. Soc.* [*London*] *A*, **66**, p. 541 (1953).

(2) Compton, A. H., and Allison, S. K. *X-rays in T and Experiment*, 2nd Ed. (New York: D. Van Nos Inc., 1948).

(3) Landon, V. D. *Proc. Inst. Radio Engrs*, **29**, p. 50 (

(4) Lang, A. R. *Proc. Phys. Soc.* [*London*] *A*, **65**, p (1952).

Calorimetry by the method of mixtures

By D. W. Plester, B.Sc., Ph.D., A.R.I.C., S. E. Rogers, B.Sc., Ph.D., A.R.I.C., and
Prof. A. R. Ubbelohde, M.A., D.Sc., F.R.S., Imperial College of Science and Technology, London, S.W.7

[*Paper first received* 14 *December*, 1955, *and in final form* 6 *February*, 1956]

A vacuum calorimeter is described, suitable for measuring heat contents of condensed phases at high temperatures. The heat of fusion of potassium thiocyanate has been evaluated as $H_f = 3 \cdot 39 \pm 0 \cdot 05$ kcal/mol. (mean deviation).

e have been extensive determinations of heat contents in it years by vacuum calorimetry, using electrical heat t devices, under adiabatic or isothermal conditions. At temperatures this method is simple and capable of high racy. Well above room temperature, however, various ections for unsuppressed heat exchange between the rimeter and its surroundings by radiation and conduction to introduce undesirably large uncertainties. It often mes inconvenient to provide for rapid and effective heat ange between various components of the calorimeter . Furthermore, in solids at higher temperatures there transformations whose relaxation time is comparatively . This introduces further uncertainties about heat ange between the calorimeter and its surroundings, h can only be overcome by allowing sufficient time to h equilibrium at any one temperature.

or heat content measurements at higher temperatures e are a number of advantages in using a modification of classical method of mixtures. The body to be studied be maintained for as long as required at the temperature ieasurement, and does not have to be fitted with compli- d heating or temperature measuring devices. It can then ansferred very promptly and under controlled conditions vacuum to the calorimeter proper, which can itself remain pproximately room temperature, or in some other thermo- ed enclosure if a different reference temperature is ired. This minimizes uncertainties about heat losses.

itegral heat content measurements have been carried out, g the method of mixtures, by a number of workers of se work representative examples are given.(1–4) Rather r workers have attempted to find heats of fusion by this ns.(5–8) A complication in any mixture method arises n the rapid cooling which follows transfer from the ace to the calorimeter produces a metastable form of the ple which may change to the stable form only very slowly.

he present paper describes a method of mixtures designed determining the latent heat of fusion of ionic crystals. sonable accuracy (mean deviation better than ±1·5%) simplicity and speed of operation and assembly has been eved based on a novel combination of design features.

PRINCIPAL FEATURES OF DESIGN

) Mercury is used as the calorimetric liquid to minimize ooration and condensation errors.(2) Its non-adherence he sample container permits repeated runs to be done out dismantling the apparatus. For higher reference oeratures other molten metals may be used. The oerature of the calorimetric liquid is measured by a mistor resistance thermometer. The calorimeter is mally isolated from the furnace by a water jacket and, quired, by two removable radiation screens.

) Transfer of the sample capsule is by means of a fine rod to which it is permanently attached. This arrange- t allows it to enter the calorimeter at a considerably r velocity than by the more usual method of dropping. Thermal conduction along the steel rod is negligible. The rounded end of the sample container obviates splashing. Heat loss during transfer is minimized by evacuation, to less than 10^{-4} mm of mercury, and by the speed of the transfer operation, which can be completed in less than one second.

(*c*) The sample container is fitted with special fins to enable stirring of the calorimeter liquid and to equalize temperature differences more rapidly.

CONSTRUCTION DETAILS

The apparatus (Fig. 1) consists basically of two stainless steel cylindrical containers *A* and *B* provided with flanges for bolting together. The lower portion *A* contains the Dewar flask *C* filled with the calorimetric liquid, while the upper tubular portion *B* houses the sample container *D* in its initial position and is surrounded by an electric furnace *E*.

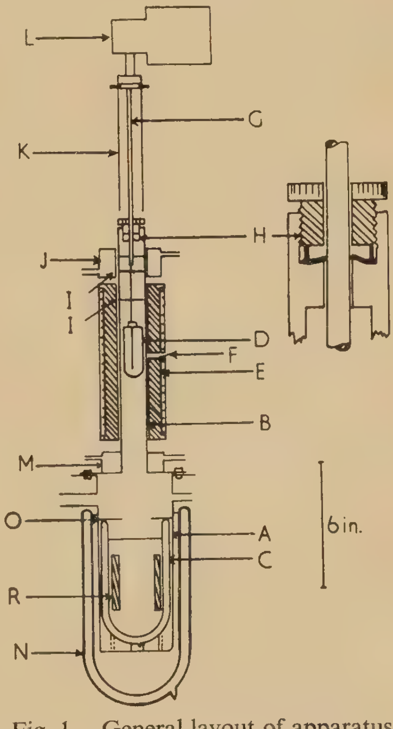


Fig. 1. General layout of apparatus

The length-to-bore ratio of the furnace was made 12 : 1 which ensured that the zone containing the capsule was maintained isothermal within a mean deviation of ±0·5° C. The temperature was controlled by Simmerstat (by Sunvic Controls Ltd.) to ±0·5° C. Better control can readily be achieved with standard electronic devices if required. Temperature was measured to ±0·05° C by means of a Johnson–Matthey Pallador thermocouple *F*.

The sample container is a stainless steel tube machined from a block, with walls as thin as possible (about 1 mm) for low heat capacity. The top was sealed with a screw-cap, with a washer of Super Golden Walkerite (by J. Walker and Co. Ltd.).

A steel plunger *G* enters the top of tube *B* through a Wilson(9) vacuum sliding seal *H*, and is connected to the sample container by a fine stainless steel rod 1 mm thick. This rod can also carry radiation shields *I*, but at the temperatures used heat exchange between the furnace and the calorimeter was not sufficient to warrant this complication. The Wilson seal is thermally isolated from the furnace by the water jacket *J*.

An extendable stirrer *K* consists of a brass tube with two longitudinal slits diametrically opposite. In these an attachment fitted to the plunger *G* can slide up and down. The sample capsule is lowered into the calorimeter before the stirring motor *L* is switched on. At the speed of stirring used (30 rev/min) no heating effect could be detected. A water-jacket *M* gives thermal isolation of the furnace from the calorimeter.

Fig. 2 shows in detail the main calorimeter with the capsule in the lowered position. The stainless steel can *A* is surrounded by water in a large vacuum flask *N*. A smaller Dewar vessel *C* is a neat fit inside *A* and contains about 130 ml. of mercury. The steel lid *O* has a central hole to allow passage of the sample capsule *D*. It also carries the thermistor resistance thermometer *P* (Stantel type F 2311/300 by Standard Telephones and Cables Ltd.) which was calibrated and used according to standard procedures.(10)

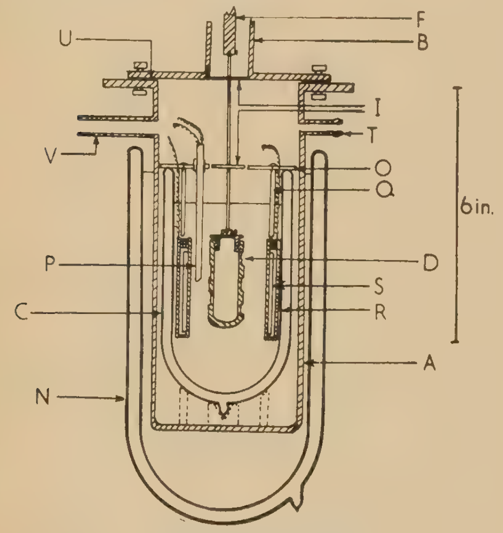


Fig. 2. Details of calorimeter

Attached to the underside of the lid are two Tufnol spacers *Q* which keep the electrical calibration heater *R* immersed in the mercury. The heater (approximately 5 Ω) is cylindrical and consists of 22 s.w.g. Brightray resistance wire wound in grooves on a tubular anodized(11) aluminium former *S*. This former is sealed into a thin steel jacket with Bostik sealing compound through which the electrical leads are taken.

The calorimeter is evacuated through the nozzle *T*, a rubber gasket *U* being used as a seal where the upper and lower portions are bolted together. Electrical leads are taken out through the tube *V* containing a wax seal.

USE OF THE CALORIMETER

To carry out a heat content determination the s container, filled with the solid under investigation, is to its position in the furnace and allowed to reach th equilibrium with it. To speed up this operation the app can be kept full of hydrogen or helium, which is only evac just before lowering the capsule into the calorimeter.

Typical temperature-time curves were obtained heat exchange corrections were determined by sta procedures.(12)

The calorimeter has been used to measure the he fusion of potassium thiocyanate (m.p. 175·1° C). A of heat content measurements was carried out on sa of 3 g at temperatures below and above the melting Two straight lines were fitted by least squares to the obs points, and the mean deviations of their parameters calculated. The heat of fusion was obtained by extrapol of the two lines to the melting point (Fig. 3). The calcu value of the latent heat of fusion of potassium thiocyan $H_f = 3\cdot39 \pm 0\cdot05$ kcal/g mol. (mean deviation) which responds to an entropy of fusion, $S_f = 7\cdot56 \pm 0\cdot10$ kcal/ °C (mean deviation).

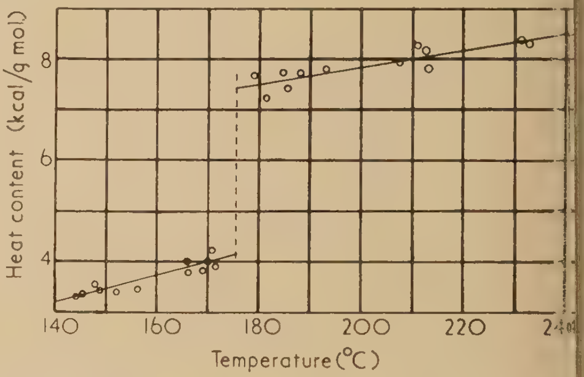


Fig. 3. Heat content curves for solid and fus potassium thiocyanate

REFERENCES

(1) ANDREWS, D. H., LYNN, G., and JOHNSTON, J. *J. A Chem. Soc.*, **48**, p. 1274 (1926).

(2) ADAMS, A. B., BROWN, R. S., BARNES, W. H., MAASS, O. *Canad. J. Res. B*, **17**, p. 341 (1939).

(3) MOSESMAN, M. A., and PITZER, K. S. *J. Amer. C Soc.*, **63**, p. 2348 (1941).

(4) SOUTHARD, J. C. *J. Amer. Chem. Soc.*, **63**, p. (1941).

(5) WERNER, A. C. *Rev. Sci. Instrum.*, **22**, p. 245 (195

(6) GOODWIN, H. M., and KALMUS, H. T. *Phys. Rev.* p. 1 (1909).

(7) AWBERY, J. H., and GRIFFITHS, E. *Proc. Phys. [London]*, **38**, p. 378 (1925–6).

(8) YOUNG, F. E., and HILDEBRAND, J. H. *J. Amer. C Soc.*, **64**, p. 839 (1942).

(9) WILSON, R. R. *Rev. Sci. Instrum.*, **12**, p. 91 (1941).

(10) BECKER, J. A., GREEN, C. B., and PEARSON, G. *Trans Amer. Inst. Elect. Engrs*, **65**, p. 711 (1946).

(11) MURPHY, G. W. *Rev. Sci. Instrum.*, **20**, p. 372 (19

(12) WEISSBERGER, A. (Ed.). *Physical Methods of Org Chemistry*, Vol. 1, p. 337 (New York: Intersci Publishers Inc., 1945).

The measurement of frictional forces at vibrating contacts

By J. S. Halliday, Ph.D., A.Inst.P., Associated Electrical Industries Ltd., Aldermaston, Berks.

[*Paper received* 1 *November*, 1955]

A simple machine is described which is used for the investigation of wear phenomena at vibrating contacts. It is shown theoretically how the frictional forces at the contacts can be measured and the experimental tests substantiate the theory. Some friction measurements are given which were obtained using brass specimens immersed under silicone oils having a wide range of viscosities. It was found that the friction was least for the medium viscosity oils. The higher friction with the high viscosity oils arose because these oils were pushed aside from the contacts, and with the lowest viscosity oils because they were not as effective in preventing the growth of intermetallic welds as the medium viscosity oils.

nachinery and metal structures it often happens that two nponents which are supposedly relatively at rest in fact rate over each other. Several names have been used to cribe the damage arising from this minute oscillatory ping action, e.g. fretting corrosion, false brinelling and tion oxidation. Very few measurements have been made this form of damage and the nature of the processes of ır still remain undecided. The majority of the experimental rk has been qualitative in character and whilst such ervations can be of great assistance, quantitative measure- nts are more likely to lead to precise interpretation of the cesses involved. It is only recently that Wright(1) and ıg and Uhlig(2) have determined the extent of fretting rosion between steel specimens quantitatively and as yet coefficient of friction during vibration has seldom been asured. A simple wear machine is described here which the important feature that measurements can be made the coefficients of friction during the course of the experi- nts. The driving power for the machine is provided by a odman type 390A vibration generator which allows a ximum movement between the specimens of 0·05 in. and ange of vibration frequencies from 10 to 10000 c/s.

One practical application of the machine is described. asurements have been made of the friction between rating brass specimens when immersed under a series of cone oils having viscosities ranging from 1 to 10^5 centistokes. was found that the least friction arose when using the dium viscosity silicones.

DESCRIPTION OF THE WEAR MACHINE

Fig. 1 shows the general layout of the apparatus as embled for an experiment. The specimens are in the form a cylindrical sleeve *C* (outer diameter 1 in., inner diameter n., length ½ in.) and two flat pads, which are supported on sides of a V-block, as illustrated in Fig. 2. Thin rubber ips are placed beneath the pads so that they aline themves with the cylinder when the load is applied and then the ds are held in position by the arrangement of screws and ms shown in Fig. 2. Thus, when the machine is assembled re is a line of contact between each pad and the cylinder. e ends of the V-block have been closed so that the specimens ı be immersed under a lubricant.

The vibration wear is produced by oscillatory rotation of cylinder about its axis, the driving force for this motion ing provided by a Goodman type 390A vibration generator (Fig. 1). The armature of G_1 is linked to the cylinder by ans of the yoke *Y* and the lever *K*. Thus the wear movents between the pads and the cylinder are at right-angles the lines of contact, and, since the effective length of the er is 5 in., these movements are ten times smaller than the movements of the yoke. The maximum movement of the yoke is 0·5 in., being limited by the armature supports in G_1.

The load between the cylinder and the pads is applied to the common shaft, which passes through the lever and the cylinder by means of the bearings *B* and the linked couplings *Q*. The bearings, lever and cylinder are clamped firmly together so that there is no possibility of slip between the cylinder and the lever.

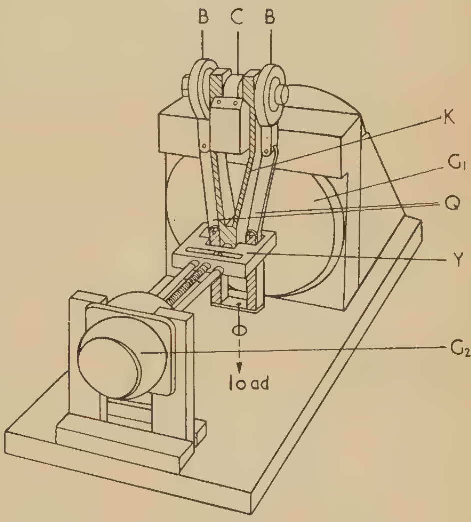


Fig. 1. General view of wear machine

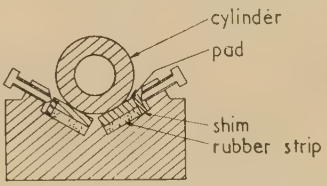


Fig. 2. Diagram showing the lower specimen positions

The movements of the yoke, which are the result of the driving force from G_1 and the various resistive forces due to friction, are detected by means of a Goodman V47 generator G_2. The movements of the generator armature induce voltage variations across its windings and the r.m.s. value of this voltage v, is measured by a millivoltmeter, the operation of which is independent of the vibration frequency ν. The millivoltmeter has been calibrated directly in terms of the total amplitude of movement of the yoke ($10a$) for various operating frequencies. The voltages induced across G_2 are also displayed on an oscilloscope in order that the frequency can be checked and so that the movements of the yoke can be followed more closely.

THE METHOD OF MEASUREMENT OF THE FRICTIONAL FORCES

In order to describe the experimental measurement of the frictional forces it is first necessary to consider in some detail the motions of the moving parts of the apparatus. To obviate continual enumeration of all the parts which move, the yoke is referred to as representing them all.

The driving force imposed on the yoke is governed by the current passing through G_1. If this current is represented by

$$I = -I_0 \sin \omega t \tag{1}$$

where $\omega = 2\pi\nu$, the instantaneous driving force is given by

$$P = -\alpha i_0 \sin \omega t \tag{2}$$

where α, which is dependent on ω, is the force constant of G_1.

The movement of the yoke is opposed by the frictional forces which arise at the specimen contacts and in the bearings B. If μ_b is the coefficient of friction in the bearings and r_b their effective radius and if μ is the coefficient of friction at the specimen contacts, the force resisting the motion of the armature is

$$F = (\mu_b r_b + \mu r \sec \theta) W/l \tag{3}$$

where r is the cylinder radius, l the lever length, θ the slope of the sides of the V-block (30°) and W is the total vertical load. The resultant force, obtained after taking due account of the phase relationships between P and F, causes the vibratory movements at the specimens.

If J is the moment of inertia of the lever and cylinder about the cylinder axis, then the force acting along the axes of the armatures which is required to rotate the cylinder about its axis with an angular acceleration $\ddot{\phi}$ is

$$R = (J + ml^2)\ddot{\phi}/l$$

where m is the mass of the cylinder and lever assembly. If $\ddot{x}$ is the corresponding linear acceleration of the yoke, then for small displacements $x = l\phi$ and hence

$$R = (J + ml^2)(\ddot{x}/l^2) = M_1\ddot{x}$$

If M_2 is the mass of the armatures of G_1 and G_2, the yoke and coupling, then the total effective mass which is acted upon by the resultant of P and F is $M = M_1 + M_2$.

Thus in circumstances when the friction is negligibly small, i.e. $F = 0$, we have that

$$P = M\ddot{x} \tag{4}$$

and x must be given by

$$x = x_0 \sin \omega t \tag{5}$$

where

$$x_0 = \alpha I_0/M\omega^2 \tag{6}$$

Hence, when there is no appreciable friction, the total movement of the yoke is $2x_0 = 10a$, where a is the total movement of the specimens. Now the r.m.s. voltage output, v_1, from G_2 is proportional to the r.m.s. velocity of the armatures. This can be found by substituting for P from equation (2) into equation (4) and integrating, giving

$$v_1 = (\alpha i/M\omega)\beta \tag{7}$$

where i is the r.m.s. current input to G_1 and β is a con
Naturally, as $F = 0$, v_1 is independent of W.

When F becomes appreciable it is assumed that
independent of the sliding velocity. Let us conside
forward stroke of M, i.e. $\dot{x} > 0$, in which case

$$\left.\begin{aligned} M\ddot{x} &= -\alpha I_0 \sin \omega t - F \\ \text{or} \qquad \ddot{x} &= -e \sin \omega t - f \\ \text{where} \qquad e &= \alpha I_0/m \quad \text{and} \quad f = F/M \end{aligned}\right\}$$

Equation (8) can be integrated provided that the
interval is restricted to the time taken for the forward st
At the beginning and end of this period the function i
continuous, due to the abrupt change in direction
Remembering this limitation, we have that

$$\dot{x} = (e/\omega) \cos \omega t - ft + c$$

where c is a constant. When $\dot{x} = 0$ and $\ddot{x} < 0$, at a ti
then x is a maximum; these conditions are satisfied wh

$$c = ft_1 - (e/\omega) \cos \omega t_1$$

Since the movement of M is cyclic and has the an
frequency ω, $\dot{x}$ must also be zero at a time $[t_1 - (\pi$
Thus the time interval over which equation (8) is conti
is from $[t_1 - (\pi/\omega)]$ to t_1. Also the value of c mu
unchanged on substitution of $[t_1 - (\pi/\omega)]$ for t_1 in equ
(10), which leads to the following relations:

$$\cos \omega t_1 = f\pi/2e$$

and

$$c = (f/\omega)\left[\cos^{-1}(f\pi/2e) - (\pi/2)\right]$$

The r.m.s. velocity of M is given by

$$\frac{\pi}{\omega}\int_{[t_1-(\pi/\omega)]}^{t_1} \dot{x}^2 dt = \frac{v_2^2}{\beta^2}$$

where v_2 is the r.m.s. voltage output from G_2 in the pres
of friction. By combining equations (7), (9) and (13) an
substitution for c from equation (12) we eventually find

$$\left(\frac{v_2}{v_1}\right)^2 = 1 - \frac{f^2}{e^2}\left(4 - \frac{\pi^2}{6}\right) = 1 - 2{\cdot}356\frac{f^2}{e^2}$$

In order to consider the reverse stroke of M we need
advance the origin of the time scale by π/ω and subst
for equation (8)

$$\ddot{x} = e \sin \omega t + f$$

Then, on evaluating

$$\frac{\omega}{\pi}\int_{[t_1-(\pi/\omega)]}^{t_1} \dot{x}^2 dt$$

the same ratio for $(v_2/v_1)^2$ is obtained as that give
equation (14). Thus, if various values are assumed fo
then t_1 and c are known and hence values of v_2/v_1 ca
evaluated using equation (14).

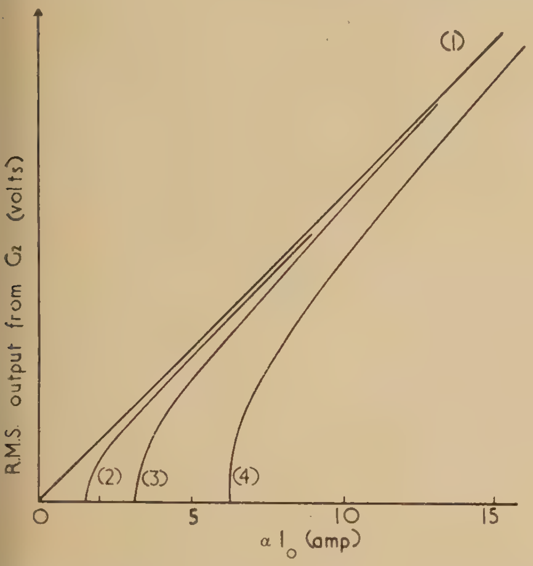
To calculate the amplitude of movement of the y
equation (9) must be integrated between $[t_1 - (\pi/\omega)]$ an
After this operation and substitution for c from equation
and $\cos \omega t_1$ from equation (11) it can be found that

$$x_F = \frac{e}{\omega^2}\left(1 - \frac{f^2\pi^2}{4e^2}\right)^{\frac{1}{2}} = \frac{\alpha I_0}{M\omega^2}\left(1 - \frac{F^2\pi^2}{4\alpha^2 I_0^2}\right)^{\frac{1}{2}}$$

where x_F represents the amplitude of movement of the
in the presence of friction. From equation (15) it can

that if $I_0 \gg F$ then $x_F = x_0$, as given by equation (6), also that when I_0 is decreased then slipping will cease n $2\alpha I_0 = \pi F$.

n Fig. 3, curve (1) has been drawn to represent the variation $_1$ with αI_0, for one given frequency. Curves (2), (3) and represent the variations of v_2, at the same frequency, as dicted by equation (14) and assuming different values of



ig. 3. Theoretical variation of the r.m.s. voltage output from G_2 for various currents through G_1

Curve (1), $F = 0$; curve (2), $F = 1$; curve (3), $F = 2$; curve (4), $F = 3$.

In all cases v_2 becomes zero when $\pi f = 2e$, as expected n equation (15). From this result it is clear that the best to determine the frictional forces experimentally, is ier to start with a very small current and then to gradually rease it until the output from G_2 suddenly increases or, rnatively, to lower the current through G_1 from a large ue until the output from G_2 suddenly drops.

t the critical current i_k we have that

$$F = (2\alpha I_0/\pi) = (2\sqrt{2}/\pi)\,\alpha i_k \tag{16}$$

n practice the voltage output from G_2 will not become o for currents smaller than i_k because there will be some stic straining of the cylinder and pads.

oincident with the change in v_2 at the critical current i_k, re will be a change in the output waveform of G_2 because ilst there is a slight amount of slipping, the motion of the e is not simple harmonic, but when the slipping ceases the specimens deform elastically, the motion of the yoke imple harmonic. There is a third way in which the change- r from slipping to straining can be detected and that is the noise emitted by the apparatus. When the specimens slipping a proportion of the work done against friction is iverted into sound and when slipping ceases this source of se abruptly finishes.

EXPERIMENTAL

arious experiments have been made to test the above oretical analysis. In the first instance, by running the chine without the lever and cylinder assembly, it was verified that v_1 was proportional to i/v in accordance with equation (7). Then the variations of v_2 with i were determined. The experimental results, obtained using aluminium specimens immersed under B.P. paraffin oil, are plotted in Fig. 4 and, on comparison with Fig. 3, it can be seen that there is good agreement between the experimental results and the theory. The linear variation of the critical current i_k with load is shown by the results in Fig. 5, in this case for

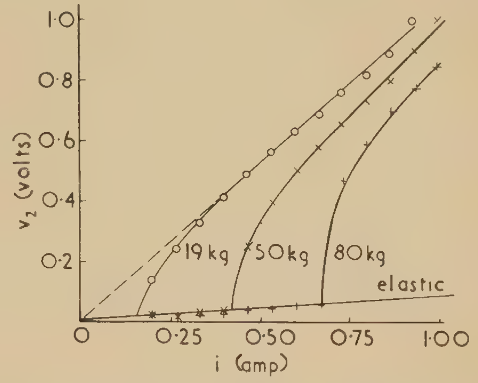


Fig. 4. Variation of G_2 output, v_2, with current input to G_1, i, using aluminium specimens under B.P. paraffin, $\mu = 0{\cdot}22$

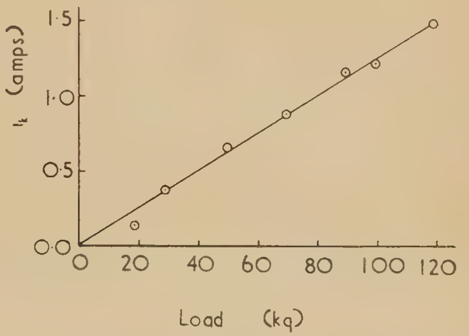


Fig. 5. Variation of the critical current i_k with load brass on brass under silicone ($\eta = 100$) at 50 c/s, $\mu = 0{\cdot}33$

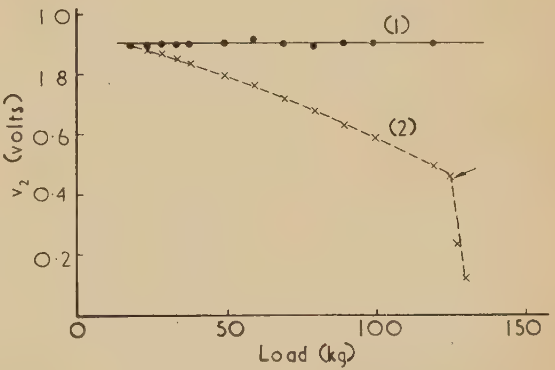


Fig. 6. Variation of the r.m.s. voltage output from G_2 with applied load, for a constant current input to G_1

Curve (1), steel cylinder on polytetrafluorethylene pads under cetane; curve (2), copper cylinder and pads under B.P. paraffin ($\mu = 0{\cdot}32$).

The arrow indicates the point of load above which slipping ceased.

naval brass specimens vibrated under a silicone oil (MS 200, 100 cS.)

The frictional forces in the bearings *B* were next determined since they affect the measurements of μ. In order to do this a very hard chrome bearing steel cylinder was used with solid polytetrafluorethylene pads and also the V-block was filled with cetane, these conditions were selected in order to minimize the frictional forces at the vibration contacts. Measurements of v_2 were made for a wide range of loads using a fixed input current *i*. The results obtained are shown in Fig. 6 where it can be seen that v_2 remained constant for all loads. Thus, within the limits of experimental accuracy, both μ for the specimens used and μ_b are negligible. For comparison, the v_2 variations with load which were obtained when using copper specimens under B.P. paraffin have been included in Fig. 6; the form of these latter variations is as expected from equation (14). Since μ_b is negligible, by combining equations (3) and (16) and substituting the known values of the constants, we have that

$$\mu = \frac{2\sqrt{2}l}{\pi r \sec\theta}\,\frac{\alpha i_k}{W} = 7\cdot8\,\frac{\alpha i_k}{W} \qquad (17)$$

There now remains the variation of α with ν. This was determined using the experimental arrangement illustrated in Fig. 7. An extension bar *A*, with two collars, was attached to the armature of G_1. With the armature in its equilibrium position and when no load was applied, the first collar just rested against the beam, which was rigidly fixed to the base of the apparatus. At the same time, the second collar pressed against a spring steel strip, causing the electrical contact to be just closed. Thus when the load *W* was applied, the beam bent and the electrical contact became more firmly established. Then an alternating current was passed through G_1 and when this was sufficiently large the peak force developed was just greater than *W* and, during this instant, the electrical contact was broken. With this apparatus, it has been found th a given frequency the force/current ratio α remains con and that the variation of α with frequency is as sho Fig. 8.

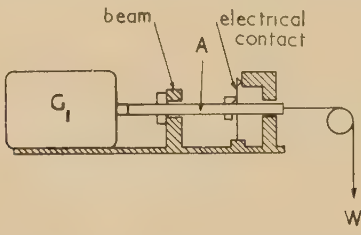


Fig. 7. Experimental arrangement for the measurement of the force constant of G_1 at various frequencies

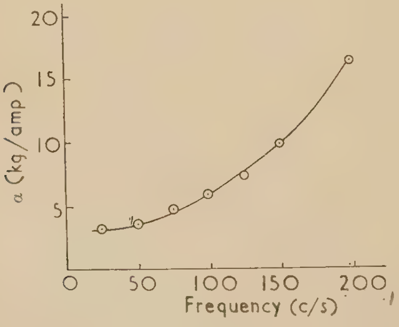
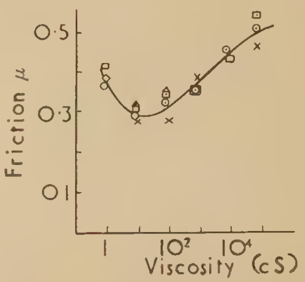


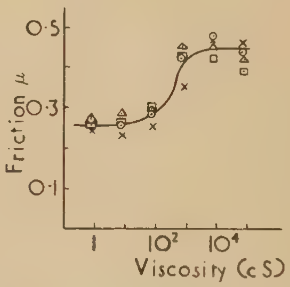
Fig. 8. Variation of the force constant of G_1 with frequency (α in peak force/r.m.s. A)

THE EFFECT OF LUBRICANT VISCOSITY ON FRICTION

In order to illustrate the use of this machine, the foll is a description of a series of friction measurements were made with brass specimens immersed under a seri silicone oils of different viscosities, all the oils havin same basic chemical structure. The results, Fig. 9(*a*), that the friction was higher for the highest and l viscosities. On dismantling the apparatus after the ex ments it was found that with the lower and mediu cosities the scars and debris were always rough and me whilst with the high viscosity oils the oil had receded the general contact regions leaving clear channels 4 mm wide and there was considerable corrosion in the Almen[3] has suggested earlier that high viscosity oils be pushed away from the contact region during vibration this would account for the high coefficient of friction obs with these oils. In attempting to discover why the fr rose for the lowest viscosity oil, a similar set of experi was carried out using silicone oils plus 10% oleic ac suspension; the friction results are shown in Fig. 9(*b*) this case the friction was again high for the higher visco but was low for all the lower viscosities, being about the as that obtained previously with the pure medium vis oils. Since the high friction with high viscosity oils i to the absence of the oils, it is to be expected that the add of some oleic acid would make no difference. Howeve reduction in friction at the lowest viscosities demons that without any additive the lowest viscosity oil di inhibit the formation and growth of intermetallic



(*a*) Silicone oils.



(*b*) Silicone oils + 10% oleic acid in suspension.

Fig. 9. Variation of friction with oil viscosity

Brass specimens. 70 kg. × = 25 c/s ○ = 50 c/
△ = 62·5 c/s □ = 75 c/

veen the rubbing brass specimens, and that the reaction ducts of the oleic acid and brass form a thin film on the ace which performs this function.

hus, although the wear scars and debris indicate that itical conditions prevail when rubbing brass specimens ther under medium and low viscosity silicone oils, the ion measurements show differences in behaviour.

ACKNOWLEDGEMENTS

he author wishes to thank Dr. W. Hirst for his continuous rest in this work, Mr. D. Rose for his assistance in the construction and use of the machine and Dr. T. E. Allibone for permission to publish this paper.

REFERENCES

(1) Wright, K. H. R. *Proc. Instn Mech. Engrs, B,* **1**, p. 556 (1952–53).

(2) Feng, I-Ming, and Uhlig, H. H. *J. Appl. Mech.*, **21**, p. 395 (1954).

(3) Almen, J. O. *Mech. Engng*, **49**, p. 415 (1937).

A wavelength discrimination spectrometer

By C. R. Forshaw, M.A., M.Sc., Sir John Cass College, London, E.C.3

[*Paper received* 16 *January*, 1956]

An improved instrument is described, in which arrangements are made for viewing a bipartite field illuminated by lights of desired wavelengths and luminances. The instrument is essentially a prism spectrometer with a double collimator, and produces spectra of high dispersion and intensity. With an artificial pupil of only 1 mm diameter, retinal illuminations of 100 photons (or trolands) can be obtained at wavelengths of 420 mμ and 690 mμ.

Some preliminary results of wavelength discrimination measurements are given to illustrate the performance of the spectrometer.

author's spectrometer was designed for the investigation the variation of wavelength discrimination under various iditions of observation. Recent investigations such as se of Weale(1) and Thomson and Trezona(2) have shown t there is a change of wavelength discrimination with iinance level and with the area of the retina stimulated. wn(3) has studied the effects of field size and colour of rounds on colour discrimination. It was therefore thought be of interest to study the effects of some of these variables the wavelength discrimination of a few observers.

lthough in the past it has been the custom to investigate roughly the colour vision characteristics of a few observers, s possible that much useful knowledge may be gained from investigation that involves the use of only one or two iables and a larger population. The common objections investigations involving a fairly large number of observers that the observations are necessarily hurried, and that the servers are unpractised in the use of precision instruments. h possible objections are overcome if the apparatus used the investigation is available in some institution where re is access to a large number of students of science. servations need not then be necessarily of a hurried nature, l the observers are to some extent practised in the nipulation of apparatus using visual fields.

he programme of work was as follows.

art (1). The investigation of wavelength discrimination many observers using a 1° foveal field, at a retinal mination of 100 trolands.

art (2). The detailed investigation of the variation of velength discrimination of a few observers with (*a*) size of d, (*b*) luminance, and (*c*) area of retina stimulated.

he present paper is confined to a description of spectrometer and the associated experimental arrange-nts, together with some preliminary results showing its formance.

1. FUNCTION OF THE SPECTROMETER

For the measurement of wavelength discrimination steps throughout the spectrum, arrangements have to be made for an observer to view a bipartite field, one-half of which is illuminated with a test light of chosen wavelength and luminance, and the other half of which is illuminated with light of which the wavelength and luminance may be varied by the observer.

2. THE BASIC OPTICAL SYSTEM

The optical system of the spectrometer was designed to be as economical in optical components as possible, without prejudice to the desired accuracy of measurements. The basic principles were used in the author's new form of anomaloscope,(4) although there is a resemblance to the system used by Shaxby.(5)

As it was desired to make experiments involving high luminance levels, and to obtain accurate measurements of wavelength discrimination at the extreme ends of the spectrum where the relative luminous efficiency of the light source is necessarily low, it was thought important that losses of light due to reflexion should be reduced by simple design. The loss of light at an untreated glass-air surface is about 4 to 5%, and thus the loss becomes considerable for a large number of optical components.

Fig. 1 shows the general arrangement of the basic optical system. Two separate slit carriages C_1 and C_2 are arranged each with its own source, condensing lenses and slit. The two carriages move along separate parallel tracks placed one above the other. (A front view of this arrangement is shown in Fig. 2.) For each system the source is a 12 V, 48 W Mazda projector lamp. The filament is placed with its axis horizontal, and the light from it is focused by two planoconvex lenses, 5 cm diameter, on to a slit of adjustable width.

Light from the illuminated slits S_1 and S_2 is collimated by the achromatic lens L of diameter 2 in. and is then dispersed by two dispersing prisms A_1 and A_2 of height 2 in. and length of side $2\frac{3}{4}$ in. These prisms are arranged to give minimum deviation to sodium light, the total deviation being about 120°. After dispersion the light traverses a biprism b, and is focused by the achromatic objective lens O to form an image at P. The image in the focal plane of O consists of four separate spectra, as shown diagrammatically in Fig. 3, since two spectra are produced by the action of the biprism b on the light from each of the slits S_1 and S_2.

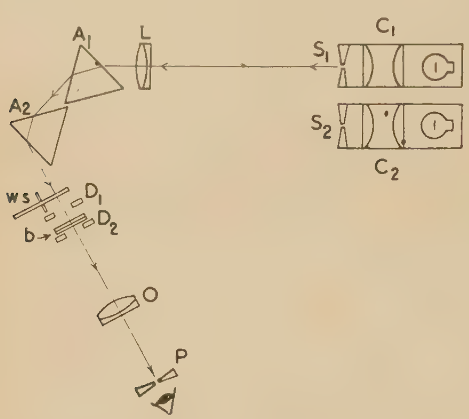


Fig. 1. Basic optical system of spectrometer

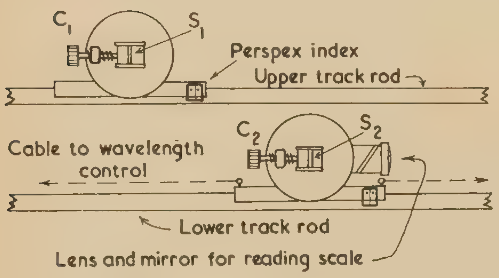

C1
S1
Perspex index
Upper track rod
C2
S2
Cable to wavelength control
Lower track rod
Lens and mirror for reading scale

Fig. 2. Front view of slit carriages

The vertical distance between the two slits is arranged so that the spectra (2) and (3) in Fig. 3 are touching. If the levelling of the optical system is correct, an eye placed at the exit pupil at P sees in Maxwellian view the horizontal dividing edge of the biprism b. This biprism then acts as a photometer prism, the upper and lower halves of which are illuminated by light from spectrum (2) and spectrum (3) (Fig. 3) respectively.

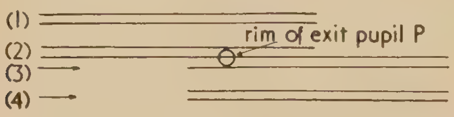


Fig. 3. Spectra focused in the plane of P. (1), (2), from slit S_2; (3), (4), from slit S_1

When the slit carriages C_1 and C_2 are moved along their tracks at right angles to the axis of the collimating lens L, the spectra (2) and (3) (Fig. 3) are moved across the exit pupil at P, thus illuminating each half of the field viewed from P with light of any desired wavelength. The wavele of the light illuminating each half of the field may be d mined by noting the position of the slit carriage with res to a fixed, calibrated scale attached rigidly to the track.

The two dispersing prisms A_1 and A_2 are of extra d flint glass, and no difference could be detected in their sepa optical properties. For each, the refracting angle is 60° the refractive index for sodium light (mean of D spe lines) is 1·7014, and the mean dispersion of the C an spectral lines with respect to the D line is 0·0317. The L has a focal length 120 cm, and therefore the depth of f is sufficient to permit the necessary variation of the dist of either slit from this lens, as the slit carriage moves a its track, without serious lack of collimation. For objective lens O a choice can be made from three achrom lenses at present available, having focal lengths 120, 70 20 cm. The choice depends on the luminance level spectral purity desired.

The spectral purity of the light entering an observer's depends mainly on the relative magnitudes of the lengt the spectrum formed in the plane of the exit pupil P and diameter of the pupil. The purity also depends on the w length of the light emerging from the exit pupil and, t smaller extent, on the width of the slits S_1 and S_2. I important to note that for observers having defective co vision, the two halves of the field may be illuminated lights of very different spectral purity, if an observatio being made of just noticeably different hue in a part of spectrum for which the observer's discrimination is poo

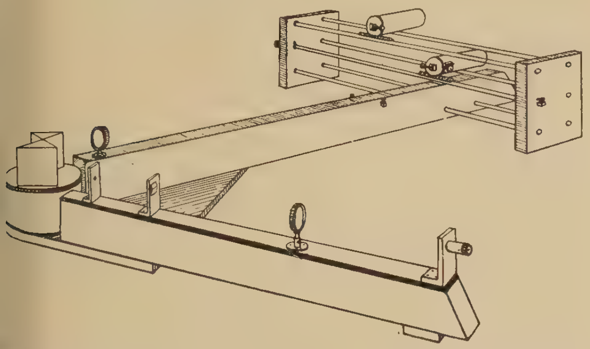
Using the lens of 20 cm focal length for the objective the spectrum formed in the plane of P is about 19 cm l between the wavelengths 750 mμ and 400 mμ. The pupil at P is of diameter 1 mm, and admits to the eye a of wavelengths not exceeding 6 mμ in the red and 2 m the blue. The movement of the slit carriages required traverse the part of the spectrum at present in use is ab 35 cm, and as readings of the associated scales can be m to 0·1 mm, the measurements of changes in wavelength accurate to 0·25 mμ in the red, and experience has sho that repeated settings of observers having good discrimina do not, in general, agree within this limit of accuracy.

The apertures in diaphragms D_1 and D_2 restrict the of the field seen by the eye placed at P. The diaphragm D in front of the biprism b, and is intended as a stop to abs the parts of the spectra not being used for the partic observation. To this end, the side of the diaphragm facing the prism A_2 is covered with a material similar to bl velvet in order that absorption of light should be as comp as possible. The aperture in this diaphragm is just la enough to admit without interference that part of the li beam required to fill the aperture in the diaphragm D_2. aperture in diaphragm D_2 is that through which passes light for the viewing field, and the aperture is circular and such a size as to restrict the field to the desired ang subtense at the eye placed at the exit pupil P.

3. CONSTRUCTION

Fig. 4 shows a general view of the arrangement of apparatus, and illustrates the construction. In Fig. 4 rotating white sector ws and field diaphragm D_2 are shown, for reasons of clarity. The present model is regar by the author as the prototype instrument, so that economy and adaptability of construction the optical syst is mounted on a wooden structure supported by an ordin heavy laboratory bench.

wo beams of wood, of rectangular section 2 by 4 in., n the collimating and viewing arms of the spectrometer. se beams are rigidly joined by an angle piece of wood . thick. The dispersing prisms A_1 and A_2 are carried on ble mounted on a levelling base made from the base of old astro-compass, which provides excellent facilities for rate levelling and slow, controlled rotation and fixing of spectrometer prism table. The slit-carriage tracks at the of the collimator arm consist of two pairs of ½ in. steel s rigidly arranged one above the other. Another pair of l rods underneath these tracks fit the track system rigidly he collimator arm.



ig. 4. General view of spectrometer with diaphragms and sector omitted

The two separate slits and their associated condensing ses and sources are mounted in 3 in. brass tubes about in. long. To the front end of each of these tubes is soldered iece of V-shaped channel steel, and to the underneath side the rear end is soldered a ball-bearing. (These fittings are wn in Fig. 5.) The inverted V-shaped channel and the ver surface of the ball-bearing form the bearing surfaces en the tubes slide along their tracks. The tubes and their ings thus form slit carriages that move at right angles to axis of the collimating lens *L* without any perceptible winging" or rocking.

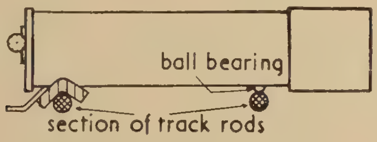


Fig. 5. Side view of slit carriage C_1

A hairline index ruled on the underside of a piece of Perspex fixed to the front end of the carriage, and passes in contact er a millimetre scale rigidly fixed to the front end of the ck. As a later refinement, to facilitate reading, the scale s illuminated and read by means of an auxiliary lens and ane mirror attached to the scale and a lamp attached to end of the frame.

The wavelength control of the upper half of the field of w consists of the rotation of a large knob fitted at the end the viewing arm. By an arrangement of cables and pulleys, tation of the wavelength control knob slides the lower slit rriage along its track. Backlash is reduced by including a rly strong spring in the cable system. Backlash cannot, of urse, affect the reading of the scale, but is important when nsidering an observer's sense of "feel" and confidence in control.

Variations in the intensity of the source are at present achieved by rheostat control of the currents passing through the projector lamps, and a control panel is situated to the right of the viewing arm of the apparatus within easy reach of the observer. The control panel contains two rheostats in parallel with each other and in series with each lamp, one rheostat for coarse and the other for fine control of the current in each lamp. An ammeter indicates the current in each lamp, the reading of the ammeters giving a rough but useful indication of the intensity of the source.

The optical system, apart from the slit system, is boxed in with plywood painted inside and out with matt black paint.

The distribution of light from one of the slits (that of the comparison light) may be altered by changing the position of the source. With the present arrangement, the light emerging from the slit is distributed mainly within a cone of roughly elliptical section. When the slit carriage moves along its track a bright oval patch of light may therefore be seen to move across the surface of the lens *L*. For normal observers making wavelength discrimination observations, the size of this patch is quite sufficient for it to cover the aperture of the collimating lens *L* over the range of movement necessary for the observation and for the maintenance of the required luminance by only small adjustments of the intensity control. However, since there is a change of light flux density within the cone, it would be expedient to arrange that the slit carriages move on tracks in the form of circular arcs with centres at or near to the collimating lens *L*, so that the same part of the light distribution from the slit falls always on *L*. The horizontal section of the focal plane of *L* is, of course, a focal curve but as the depth of focus of the lens *L* is quite large, the use of a circular arc is sufficient. Because a large amount of unwanted light is directed towards the lens *L* and the dispersing system, it is important that these components should be protected from this light by effective shielding, and that none of the unwanted light is scattered by the walls of the laboratory or surrounding objects into the collimating lens *L*.

4. CALIBRATION OF THE WAVELENGTH SCALES

Since the position of the slits on their respective tracks determines the mean wavelength of the light passing through the exit pupil at *P*, the scales attached to the tracks may be calibrated in terms of wavelength. The scales are calibrated directly in terms of the spectrum lines of mercury and cadmium vapour lamps, together with a lithium flame. The calibration is performed in two stages.

Stage (1). The appropriate calibration source is first placed at the end of the viewing arm of the spectrometer in order to illuminate the pupil at *P*, which is now used as the entrance slit and the optical system used in reverse. Spectra are then formed in the focal plane of the lens *L*, these taking the form of oval images of the circular aperture of the pupil *P*, instead of the usual line spectra obtained by use of a narrow slit. Due to the action of the biprism *b*, two spectra of the same source are formed, one above the other. The slit carriages are then moved along their tracks so that centres of the various spectral images of the pupil *P* fall in turn upon the slits. The scale readings for these positions of the slit carriages are noted, and give a preliminary rough calibration. In addition, the vertical distance between the upper and lower spectra enables the determination of the precise part of the length of the slit utilized by the optical system under straightforward working conditions, so that the lengths of both slits can be adjusted to cut down the amount of light not wanted. The vertical diameter of each image thus gives the length of slit required for the particular lens used as lens *O*; and also, the size of the horizontal axis of the image enables a check to be made on the purity of the spectral lights emerging from *P* when the system is in normal operation, as the range of wavelengths may be found from the calibration curve when the horizontal extent of the image is measured.

Stage (2). The backs of the tubes forming the body of the slit carriages are removed and an auxiliary lens used to throw an image of the calibration source on or near to the filaments of the projector lamp. When the slit carriage is placed in the appropriate position as indicated by the preliminary calibration of stage (1), the isolated lines of the spectra of the calibration sources will appear in the exit pupil at *P*. Small movement of the slit carriage along its track then causes the line image of the slit at *P* to move across the exit pupil, and a setting is made when the image is located in the centre of the pupil, as seen with the aid of an auxiliary eyepiece. This procedure is repeated for other lines, and from the readings a wavelength calibration curve can be drawn.

To assist interpolation, the variation of refractive index (μ) of the dispersing prisms with wavelength (λ) was determined, and the Cauchy formula

$$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} \qquad (1)$$

used to express the result.

Both dispersing prisms have identical values of the constants in the Cauchy formula, to the degree of accuracy of their determination. The values of the constants were determined as follows: $A = 1\cdot6754$, $B = 6\cdot928 \times 10^5$ and $C = 7\cdot285 \times 10^{12}$ for λ in Ångstrom units.

Since the variation of μ with $1/\lambda^2$ is almost linear, the term in C/λ^4 being small, the scale reading was assumed to have a quadratic relation with $1/\lambda^2$. Some slight non-linearity of the scales prevents an exact fitting of the whole calibration curve to a quadratic in $1/\lambda^2$, and accordingly an interpolation formula is calculated for each interval between calibration points.

5. LUMINANCE MEASUREMENTS

For the proposed investigation it is important to know the luminance level at which any particular observation is made. The luminance of the visual field may be determined by the methods of visual photometry or by some form of calibrated photoelectric photometer. At present the luminance of the visual field is determined by visual photometry as follows.

A rotating aluminium sector *ws* (Fig. 1) has its front surface smoked with a layer of magnesium oxide by burning a length of clean magnesium ribbon. The surface is then illuminated by means of a standard lamp of known luminous intensity, the illumination being arranged at an angle of 45°. The illumination *E* of the perfectly white, perfectly diffusing surface of the magnesium oxide is then calculated, from the inverse square law, in metre candles. The luminance *B* of the surface is then (E/π) cd/m², i.e. $(E/\pi) \times 10^{-4}$ sb. (This is taken as the luminance of the field of view which is seen alternately with the surface of the white sector when the latter is rotated at such a speed as to give no fusion, the distance of the standard lamp from the sector being varied until there is no flicker.)

As the surface of the white sector is viewed through four glass-air surfaces, the field luminance is reduced by a factor *k*, which may be calculated if the refractive indices of the glasses [of which the biprism *b* and lens *O* (Fig. 1) are made] are known. Using Fresnel's formulae for almost no incidence of the light, the fraction of the incident light by reflexion at the surface of a medium of refractive ind is $[(\mu - 1)/(\mu + 1)]^2$. For four surfaces, using $\mu = 1\cdot5$ assuming there is no absorption of light in the glass m the value of *k*, the fraction of the original incident transmitted, is then $(0\cdot96)^4$, i.e. about $0\cdot85$. Thus luminance of the field is given as

$$B = \frac{(0\cdot85)E}{\pi \times 10^4}\ \text{sb}$$

For the calculation of the retinal illuminations, it is r that the unit of one photon (or troland) is defined as retinal illumination when a surface having a brightnes 1 cd/m² is viewed through a pupil of area 1 mm². The pupil at *P* (Fig. 1) has a diameter of 1 mm and thus retinal illumination is

$$[(E/\pi) \times (\pi/4)]\ \text{i.e.}\ (E/4)\ \text{photons (or trolands)}$$

As mentioned in Section 2, various lenses may be use the objective lens *O*. The choice of lens is determine consideration of the luminance level required and of spectral purity desired. If *f* is the focal length of the obje used, the luminance varies as $(1/f^2)$ while the spectral p varies as $(1/f)$. It would therefore appear that the us fairly high luminance levels does not necessarily entail portionally high losses of spectral purity. Moreover, as variation of wavelength discrimination with spectral puri small for spectral purities of between $1\cdot0$ and $0\cdot5$(6,7 demands of high luminance and spectral purity do conflict unduly.

A change of objective lens with the present arrange necessitates the alteration of the positions of the compon mounted on the viewing arm of the spectrometer, consequent recalibration of the wavelength scales.

The width of slit at present used is $0\cdot80$ mm as meas by taper gauge, but when the long focal length objecti used considerably greater widths would not effect the p of the emergent light to any appreciable extent. The ga luminance with increased slit width may be of value in s part of the proposed investigation, but preliminary t indicate that, even with the present width of $0\cdot80$ mm, luminance is sufficiently high for glare to occur for ligh the yellow-green part of the spectrum.

6. CONDITIONS OF OBSERVATION

For wavelength discrimination observations, long per of previous dark adaption do not appear to be necessar and accordingly observations are made soon after observer has arrived at the instrument. The technique for viewing is the "glance" method of Thomson and Wrigh with fixation on the centre of the dividing edge of the bipr when foveal observations are being investigated.

Accurate centring of the observer's pupil and the artifi pupil at *P* (Fig. 1) is usually important, for there is a varia of effectiveness of light at different distances from the ce of the observer's pupil (the Stiles–Crawford effect), and as it is possible for some observers to view near the edg the exit pupil *P*, thus reducing the luminosity of the field to the effects of diffraction.

As the comfort of the observer is usually of consider importance if readings are to be reliable, the position of observer's head was not fixed by the use of a dental impres (especially as even this method does not prevent all movem e eye relative to the artificial pupil), but by means of a ed chin-rest at the appropriate height. After some initial an observer can locate the correct position for viewing naintain it for the fifteen to twenty minutes required for set of observations. The use of a head-rest fixing the ion of the temples was not found to be desirable, as this d nothing to the ease of centring the pupil or to the ort of the observer.

7. TESTING OF THE SPECTROMETER

e range of wavelengths emerging from the exit pupil at ig. 1) was at first calculated from the geometry of the m, and then by the method indicated in Section 4, in h the calibration of the wavelength scales is described. e estimates of the spectral purity were directly checked eceiving the emerging light on to the slit of an auxiliary trometer and forming a spectrum of the emerging light. spectrum consisted of an image of the circular edge of exit pupil, as the slit of the auxiliary spectrometer was ed sufficiently to allow the whole of this edge to be seen. edges of the coloured image appeared to be quite sharp, ving the effect of stray light to be small, and measurement e image diameter in a horizontal direction gave a direct hod of estimation of the range of wavelengths emerging 1 the pupil *P*.

avelength discrimination observations at a medium al illumination of about 100 trolands have been made by normal observers with fields of various angular subtense. angular subtense of the circular apertures used in the hragm at D_2 (Fig. 1) are at present 5°, 2°, 1°, 27′ and 14′. ervations are made at each of twenty-eight wavelengths ugh the spectrum. At each wavelength, five observations he same discrimination step both in the red and violet ctions are made, and also ten observations of a match of comparison and test halves of the visual field. So far, surements of wavelength discrimination have been made g each of the five different sized fields for three of the observers. Wavelength discrimination curves representthe mean curves of three observers are shown in Fig. 6.

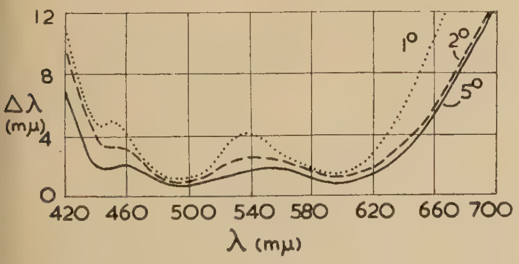


Fig. 6. Wavelength discrimination curves

m theoretical considerations, the author has concluded t the standard error of the mean of *n* measurements of a velength discrimination step (Δλ) is $[1/3\sqrt{(n-1)}](\Delta\lambda)$, calculation of the standard errors of actual measurements ports this conclusion. As the number of measurements *n* sually five, for an individual curve the standard error of is everywhere about 16% of Δλ.

rom Fig. 6 it is seen that the results of measurements made 1 the author's spectrometer give wavelength discrimination ves that do not differ significantly from those of Wright Pitt,(9) and it is concluded that the design and pernance of the new instrument here described is satisfactory use in the present investigation.

8. AUXILIARY EQUIPMENT

(a) *A further control of field luminance.* A circular neutral wedge of width 1 in. mounted on a 6 in. diameter circle can be used to reduce equally the intensity of the lights in the two halves of the field of view. This simplified control of the luminance of the comparison half of the field and enabled the running of the projector lamps under more constant conditions.

(b) *The use of a photoelectric photometer to measure the illumination of the white surround.* The utility of a photoelectric photometer for measurement of luminances was tested. An Eel selenium cell (by Evans Electroselenium Ltd.) of area 5 mm^2 was placed at the exit pupil and connected, as recommended by the manufacturers, to a galvanometer of about 1000 Ω resistance. No deflexion of the galvanometer could be detected for even the highest field luminances. However, in experiments where the field was surrounded by a magnesium oxide surface of 10° subtense at the exit pupil, another cell of area 4 cm^2 proved useful for checking estimates of the luminance of the surround made by visual photometry. For this purpose, the cell was lowered into a position facing the magnesium oxide surface and at a distance from it of 7·5 cm. The deflexions of the galvanometer were then sufficient for the luminance of the surround to be set to desired values to an accuracy almost equal to that of the visual photometric observations used in the calibration of the cell.

(c) *A duplicate observing field.* After the spectrometer had been in use for some time it was decided to make use of spectra (1) and (4) (Fig. 3) which otherwise were merely wasted light and also were possible sources of stray light, to provide the illumination for a duplicate field of observation. This duplicate field could be observed by the experimenter as a check of the appearance of the field at the actual time of observation. It was found that such a check was necessary for most observers, particularly with regard to the equality of luminance of the test and comparison halves of the field. Even observers practised in spectroscopic work found some

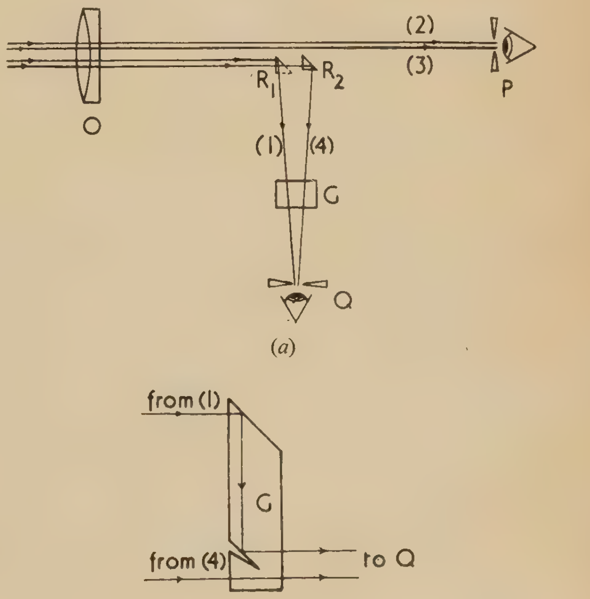


Fig. 7. (*a*) Modification to provide a duplicate observing field. (*b*) Photometer prism *G*

difficulty in equating the luminances of fields of different colour, and it was desirable that a check of the luminances could be made without inconvenience.

To provide the lights for the duplicate field, two small right-angled prisms R_1 and R_2 [Fig. 7(*a*)] were inserted in the path of the spectra (1) and (4), at positions about 6 cm in front of the artificial pupil *P* (Fig. 1), to reflect the beams at 90° to the axis of the telescope arm of the spectrometer. The two beams were then brought together by the photometer prism *G* (Fig. 7), and provided the illumination for the two halves of the duplicate field which was viewed by the eye through the artificial pupil *Q* [Fig. 7(*a*)]. The prisms R_1 and R_2 needed careful mounting in order to present the same parts of the spectra viewed by the observer with his eye at *P*. As extra air-glass surfaces were interposed in the path of the light, the luminances of the duplicate field were not equal to those of the original field. However, the retinal illuminations of the original and duplicate fields could be made equal by the use of an artificial pupil *Q* of the necessary diameter. The slightly larger diameter needed for the pupil *Q* did not change the purity of the spectra viewed at *Q* to any appreciable extent. When a normal observer viewed the original field and another observed the duplicate field, it was found that each observer could set the luminance of the two halves of the field to an equality agreed to be satisfactory by the other. The only disadvantage of the use of the duplicate field was that the observer at *Q* was too near to the photometer lamp illuminating the white surround of the original field for observations to be made in comfort. As observations at *Q* were made only as a quick check on the equality of luminance of the halves of the field viewed at *P*, this lack of comfor
not a matter of great concern.

ACKNOWLEDGEMENTS

The author acknowledges a grant from the Central Rese
Fund Committee of the University of London, part of w
was used to purchase the main optical components o
apparatus; and records his indebtedness to Dr. A. M. W
Principal of Sir John Cass College, for encouragement
help. Thanks are due to Mr. R. H. Humphry, Head o
Department of Physics, for advice and permission to us
resources of the department, and to Mr. G. A. Mann
valuable discussions and constructive criticism.

REFERENCES

(1) Weale, R. A. *J. Physiol.*, **113**, p. 115 (1951).
(2) Thomson, L. C., and Trezona, P. W. *J. Physiol.*, p. 98 (1951).
(3) Brown, W. R. J. *J. Opt. Soc. Amer.*, **42**, p. 37 (195
(4) Forshaw, C. R. *J. Sci. Instrum.*, **31**, p. 16 (1954).
(5) Shaxby, J. H. *Quart. J. Exp. Physiol.*, **16**, p. 373 (1
(6) Tyndall, F. P. T. *J. Opt. Soc. Amer.*, **23**, p. 15 (19
(7) Haase, G. *Ann. Phys.* [*Leipzig*], **20**, p. 75 (1934).
(8) Thomson, L. C., and Wright, W. D. *J. Physiol.*, p. 316 (1947).
(9) Wright, W. D., and Pitt, F. H. G. *Proc. Phys.* [*London*], **46**, p. 459 (1934).

An X-ray absorptiometer for the determination of tetraethyl lead in petrol

By J. F. Brown, A.R.C.S., B.Sc., Ph.D., and R. J. Weir, B.Eng., Grad.I.E.E., Imperial Chemical Industries Lt
Billingham, Co. Durham

[*Paper first received* 12 *August, and in final form* 16 *November*, 1955]

A compact X-ray set suitable for the routine determination of tetraethyl lead in petrol by absorption measurements is described. The X-ray tube, a Ferranti type B100, is operated at 25 kV and 200 μA using a projection television high tension generator, and has a short term X-ray intensity stability of $\pm 0 \cdot 3\%$. The X-ray detector consists of a phosphor and a photomultiplier. This is capable of determining the concentration of tetraethyl lead in petrol over the range 0 to 1·5 ml./l. (0 to 6 ml./Imperial gallon) with an accuracy of $\pm 0 \cdot 005$ ml./l. ($\pm 0 \cdot 02$ ml./Imperial gallon).

The amount of tetraethyl lead in a petrol can be conveniently and accurately measured by X-ray absorption.(1) It was decided to construct a compact low-power X-ray absorptiometer suitable for routine use in an industrial laboratory.

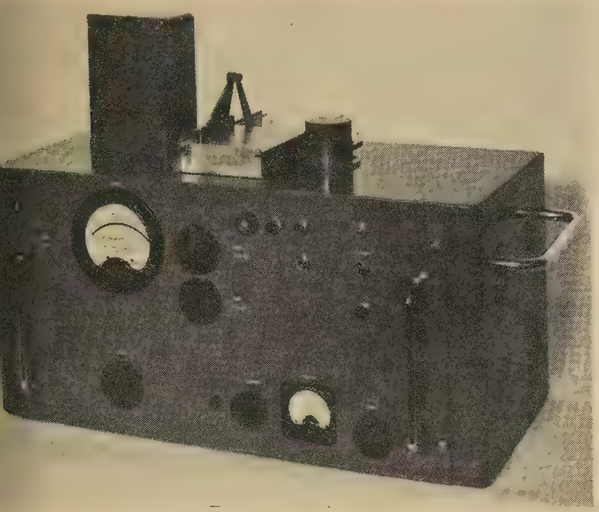
The absorptiometer consists of three main parts, a low-power X-ray set, an absorption cell and an X-ray detector. The apparatus in its final form is shown in Fig. 1. The X-ray set is built around a Ferranti type B100 X-ray tube, a small radiation-cooled triode type with a maximum anode rating of 50 kV, 25 W. The B100 filament supply is stabilized by a 30 W constant voltage transformer of the saturated core type. The tube anode supply is 25 kV and was chosen for two reasons: first the absorption coefficients of carbon and hydrogen are about equal at this voltage and hence the calibration of the apparatus will not be affected by small changes in the composition of the base petrol; and second a simple and inexpensive generator for 25 kV is commercially available for use with projection television tubes.

A stable X-ray intensity is obtained by using a st
25 kV anode supply for the tube and by controlling the b
current of the tube with a degenerative type of stabil
operating on the B100 modulator. The range of this stabil
is limited and manual control of the X-ray tube filan
current is provided to given an initial setting of the b
current within the range of the stabilizer.

The absorption cells are made in blocks of five from ro
5% silicon aluminium plate. Location of the cells in
X-ray beam is provided by a spring-loaded ball catch
detent system which positions the cells to better than $\pm\frac{1}{32}$
The cells are tapered along their length and are of circ
cross-section, 3½ in. long with a minimum diameter of
and a maximum diameter of $\frac{25}{32}$ in. The cells are fi
from one hole at the large end, the ends of the cells be
sealed by $\frac{1}{16}$ in. thick Perspex windows cemented in.

The X-ray detector is a nickel-killed zinc sulphide phosp
with an emission maximum at about 4000 Å when excited

energy X-rays. The intensity of the light produced by hosphor is determined by measuring the photomultiplier ctor current with a valve circuit and moving coil meter.(2) photomultiplier and valve circuit are supplied from a lized negative supply.



ig. 1. Photograph of complete X-ray absorptiometer

ne absorptiometer is housed in a 21½ × 10½ in. case, the r for the X-ray tube collimates the beam entirely within working area. This cover can only be detached by rewing from the inside of the case. The 25 kV supply ntirely within the case, thus reducing the risk of shock minimum. The danger of explosion of petrol vapour been minimized by the provision of a well ventilated case- and by careful insulation of the high voltage points.

g. 2 is a block diagram of the absorptiometer and Fig. 3 complete circuit.

STABILITY REQUIREMENTS

It can be shown that when an X-ray beam passes through a sample of leaded petrol

$$\log_e (I_0/I_t) = KT$$

where I_t is the intensity of the X-ray beam after passing through a sample of petrol with a concentration of T ml. of tetraethyl lead/Imperial gallon (ml./I. gal) whilst I_0 is the intensity of the X-ray beam after passing through a similar sample containing no lead; K is a constant depending on the experimental conditions. It was found that at 25 kV and a cell length of 10 cm $K = 0\cdot14$.

Now the accuracy required for the determination of tetraethyl lead in petrol over the range 0 to 6 ml./I. gal is $\pm 0\cdot02$ ml./I. gal which is equivalent to a change in X-ray intensity of 0·3%. Thus the X-ray beam intensity must be stabilized to at least this accuracy and the measuring circuit must be capable of resolving this change and must possess an inherent error of less than 0·3%.

The design of stabilizers for the X-ray tube supplies required information on the variation of X-ray intensity with tube operating conditions. The X-ray intensity can be conveniently measured with the photomultiplier unit. If low X-ray intensities are used, the light output from the phosphor is directly proportional to X-ray intensity. Under low light level conditions with low collector current, the photomultiplier output is linear with respect to incident light and hence to X-ray intensity.(3)

The X-ray intensity can be related to two variables, the anode voltage (E_a) and the beam current (I_a). From the measurements taken on the B100 X-ray tube it was found that at about 25 kV the X-ray intensity is proportional to E_a^4 and to I_a. Under conditions of fixed modulator bias voltage, I_a is proportional to $I_f^{7\cdot5}$ where I_f is the filament current. Thus with $E_a \simeq 25$ kV and fixed bias voltage the X-ray intensity is proportional to $E_a^4 I_f^{7\cdot5}$.

The gain of the X-ray detector photomultiplier and hence the indicated X-ray intensity is proportional to $E_d^{6\cdot65}$ where

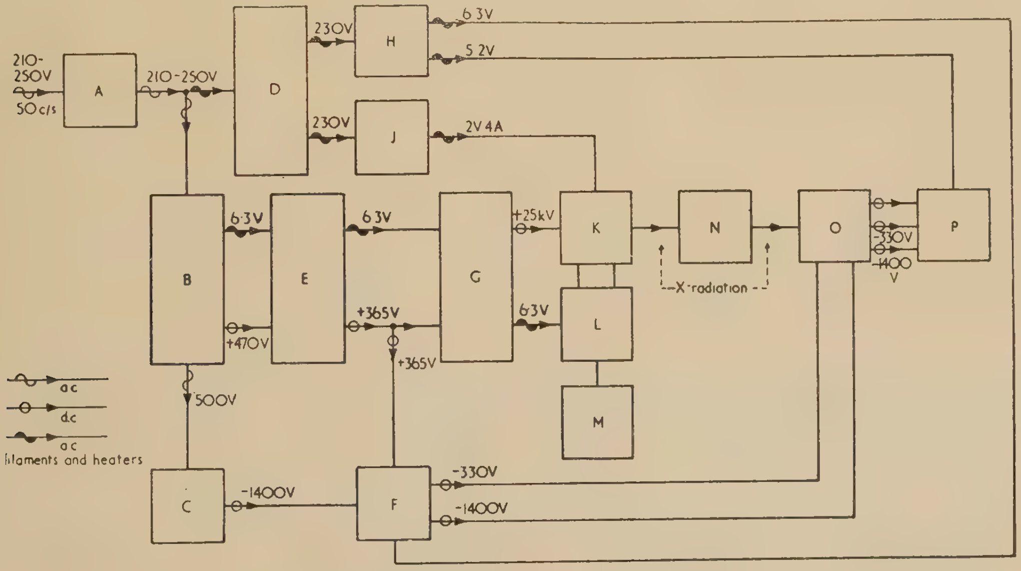
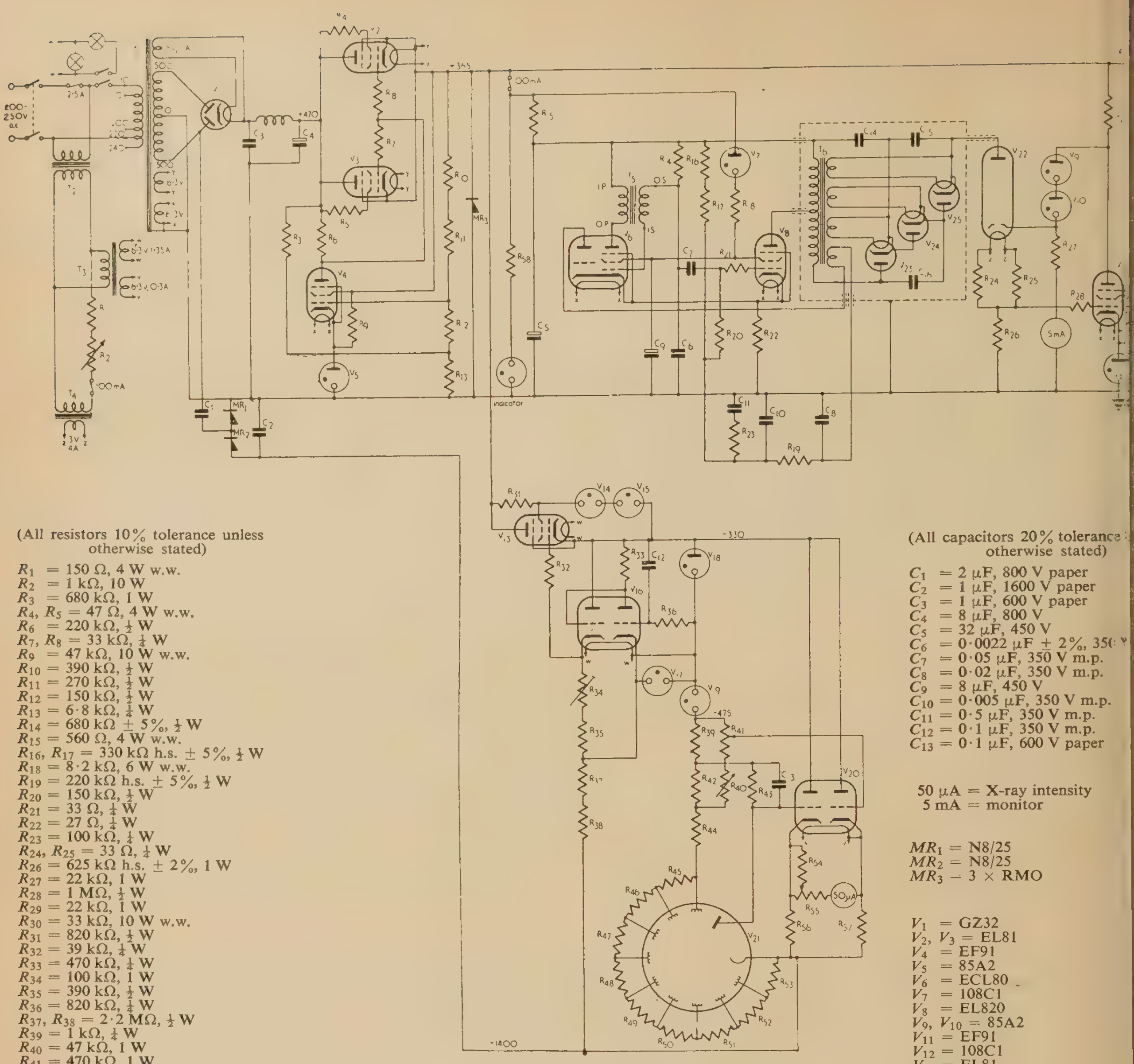


Fig. 2. Block diagram of X-ray absorptiometer

4, filament switch and fuse; *B*, h.t. switch and 470 V power pack; *C*, voltage doubler; *D*, 30 W constant voltage transformer; *E*, 365 V stabilizer; *F*, negative h.t. stabilizer; *G*, 25 kV generator; *H*, critical heater supplies; *J*, X-ray tube filament transformer; *K*, X-ray tube; *L*, beam current stabilizer; *M*, beam current monitor; *N*, absorption cells; *O*, photomultiplier; *P*, valve voltmeter.



(All resistors 10% tolerance unless otherwise stated)

R_1 = 150 Ω, 4 W w.w.
R_2 = 1 kΩ, 10 W
R_3 = 680 kΩ, 1 W
R_4, R_5 = 47 Ω, 4 W w.w.
R_6 = 220 kΩ, $\frac{1}{2}$ W
R_7, R_8 = 33 kΩ, $\frac{1}{4}$ W
R_9 = 47 kΩ, 10 W w.w.
R_{10} = 390 kΩ, $\frac{1}{2}$ W
R_{11} = 270 kΩ, $\frac{1}{2}$ W
R_{12} = 150 kΩ, $\frac{1}{2}$ W
R_{13} = 6·8 kΩ, $\frac{1}{4}$ W
R_{14} = 680 kΩ ± 5%, $\frac{1}{2}$ W
R_{15} = 560 Ω, 4 W w.w.
R_{16}, R_{17} = 330 kΩ h.s. ± 5%, $\frac{1}{2}$ W
R_{18} = 8·2 kΩ, 6 W w.w.
R_{19} = 220 kΩ h.s. ± 5%, $\frac{1}{2}$ W
R_{20} = 150 kΩ, $\frac{1}{2}$ W
R_{21} = 33 Ω, $\frac{1}{4}$ W
R_{22} = 27 Ω, $\frac{1}{4}$ W
R_{23} = 100 kΩ, $\frac{1}{4}$ W
R_{24}, R_{25} = 33 Ω, $\frac{1}{4}$ W
R_{26} = 625 kΩ h.s. ± 2%, 1 W
R_{27} = 22 kΩ, 1 W
R_{28} = 1 MΩ, $\frac{1}{2}$ W
R_{29} = 22 kΩ, 1 W
R_{30} = 33 kΩ, 10 W w.w.
R_{31} = 820 kΩ, $\frac{1}{2}$ W
R_{32} = 39 kΩ, $\frac{1}{4}$ W
R_{33} = 470 kΩ, $\frac{1}{4}$ W
R_{34} = 100 kΩ, 1 W
R_{35} = 390 kΩ, $\frac{1}{2}$ W
R_{36} = 820 kΩ, $\frac{1}{4}$ W
R_{37}, R_{38} = 2·2 MΩ, $\frac{1}{2}$ W
R_{39} = 1 kΩ, $\frac{1}{4}$ W
R_{40} = 47 kΩ, 1 W
R_{41} = 470 kΩ, 1 W
R_{42} = 10 kΩ, $\frac{1}{4}$ W
R_{43} = 25 MΩ h.s., 1 W
R_{44} = 120 kΩ, $\frac{1}{4}$ W
R_{45}–R_{53} = 82 kΩ, $\frac{1}{4}$ W
R_{54} = 12 kΩ, $\frac{1}{4}$ W
R_{55} = 100 kΩ, 1 W
R_{56}, R_{57} = 1 MΩ, 1 W
R_{58} = 820 kΩ, $\frac{1}{2}$ W

T_1 = Gardner's Radio type GR 18575
T_2 = advance constant voltage transformer type MT/181/A
T_3 = special filament transformer 6·3 V, 1·35 A, 5·2 V, 0·3 A
T_4 = special X-ray tube filament transformer 3 V, 4 A

T_5 = Igranic type KP 7976/1
T_6 = Mullard e.h.t. can type 10840

Indicator = 6·3 V, 0·3 A, G.E.C. type L.N.I. (neon)

(All capacitors 20% tolerance otherwise stated)

C_1 = 2 μF, 800 V paper
C_2 = 1 μF, 1600 V paper
C_3 = 1 μF, 600 V paper
C_4 = 8 μF, 800 V
C_5 = 32 μF, 450 V
C_6 = 0·0022 μF ± 2%, 35
C_7 = 0·05 μF, 350 V m.p.
C_8 = 0·02 μF, 350 V m.p.
C_9 = 8 μF, 450 V
C_{10} = 0·005 μF, 350 V m.p.
C_{11} = 0·5 μF, 350 V m.p.
C_{12} = 0·1 μF, 350 V m.p.
C_{13} = 0·1 μF, 600 V paper

50 μA = X-ray intensity
5 mA = monitor

MR_1 = N8/25
MR_2 = N8/25
MR_3 = 3 × RMO

V_1 = GZ32
V_2, V_3 = EL81
V_4 = EF91
V_5 = 85A2
V_6 = ECL80
V_7 = 108C1
V_8 = EL820
V_9, V_{10} = 85A2
V_{11} = EF91
V_{12} = 108C1
V_{13} = EL81
V_{14}, V_{15} = NT2 (Hivac)
V_{16} = ECC81
V_{17} = NT2 (Hivac)
V_{18} = 85A2
V_{19} = NT2 (Hivac)
V_{20} = ECC83
V_{21} = photomultiplier 931A
V_{22} = B100 Ferranti

Fig. 3. Circuit diagram of X-ray absorptiometer

E_d is the dynode or stage voltage; this figure being taken from the published curves for the type 931A photomultiplier.

Summarizing, therefore, it is desirable that none of the previously mentioned factors, anode voltage (E_a), filament current (I_f) or dynode voltage (E_d) should vary the indicated intensity by more than 0·3%. This means that the anode voltage should be stable to ±0·075%, the dynode voltage to ±0·045% and the beam current to ±0·3%.

CIRCUIT DETAILS

The 365 V h.t. supply. The 25 kV generator requires a 365 V h.t. supply; this is derived from a 470 V supply and is stabilized by the series valves V_2 and V_3, the amplifier and the reference V_5. The stabilization of this circu adjusted by "feeding forward" a fraction of the 470 V i to the grid of V_4 by means of the potentiometer R_3 and This potentiometer was adjusted to give optimum stabili the 25 kV supply. The rectifier MR_3 is connected across 365 V supply to prevent the reference neon tube V_5 struck in the reverse direction by current from the nega h.t. stabilizer during the warm-up period.

The 25 kV generator. The 25 kV generator is based design due to Overton and Crouch of the Mullard Rese Laboratories.(4) It consists essentially of a 1 kc/s bloc oscillator V_6 driving a power amplifier V_8 in the anod

ch is an inductive load which "rings" when the anode
rent of V_8 is switched off. These "rings" are auto-
nsformed to about 9 kV peak and rectified by a series fed
ler system of the Cockroft and Walton type. The rectifiers
d are type EY51 and the rectifier heaters are fed from
e separate windings on the ringing transformer core.
he fifth winding on the transformer is provided to monitor
amplitude of the "ring" and the potential appearing
oss it is rectified by the diode connected triode of V_6 and
to the bottom end of a potential divider $R_{16} + R_{17}$ and
. The potential at the junction of R_{17} and R_{19} controls
peak current through V_8 (assuming the drive amplitude
constant) and hence the amplitude of the "ring." The
dback voltage change at the grid of V_8 is about 0·75
es the voltage change across the monitor winding and
duces a negative output resistance on the 25 kV supply.
increase the output resistance to zero a compensating
tage is developed across R_{15} so that as V_8 anode current
reases, the voltage applied to $R_{16} + R_{17}$ falls. The
ultant variation of output from the 25 kV supply is less
n ±0·2% for load variations of 100 to 300 μA.(4) The
bility of the 25 kV output is a function of the stability of
365 V h.t. line and of the heater supply to V_6 and V_8.
e overall stability is ±0·085% for mains voltage variations
±10%.
The B100 filament supply. The filament supply is taken
m a saturated core transformer which stabilizes the
ment supply voltage to ±0·7% for ±10% mains variations
±0·5% frequency variations. During the first ten
nutes of operation the filament current required for
nstant emission changes by about 5% and manual control
the filament current is provided for adjustment during
s period.
The beam current stabilizer. The requirements for beam
rent stability is ±0·3% and to obtain this a beam current
bilizer operating on the modulator of the B100 is used.
e circuit compares the voltage developed across R_{26} by
beam current with that across the neon tube V_{12}, amplifies
difference and feeds the amplified difference back on to
B100 modulator. The circuit improves the beam current
bility by a factor of about forty over the range ±0·5% I_a.
e beam current monitor records the potential of the B100
dulator and has a deflexion equivalent to ±0·5% I_a. The
m current is stable to better than ±0·15% after the first
minutes of operation.
The negative h.t. stabilizer. The supply for this stabilizer
taken from between the +365 V stabilized line and the
1400 V line. The stabilizer is based on an original circuit
e to McKenzie.(5) In this circuit, V_{16} with its associated
hode resistances and the reference V_{18}, give a zero a.c.
istance between V_{13} cathode and the −1400 V line.
anges of current through V_{16} are used to control the
ies valve V_{13}; these current changes in V_{16} result in the
ve constants changing and hence a departure from zero
. resistance for the circuit. The stability achieved is
)·01% for ±10% mains variation. The neon tube V_{17}
otects the heater cathode insulation of V_{16} during the
rm-up period.

The photomultiplier circuits. The type 931A photomultiplier is supplied with about 900 V and the collector potential is measured by V_{20} and indicated on a 50 μA, 3½ in. moving coil meter. Zeroing potentials are provided by R_{40} and R_{41}; a reciprocal law sensitivity control is given by R_{54} and R_{55}. The sensitivity is adjustable from 5 V between V_{20} cathodes to a maximum of 0·6 V.

OVERALL PERFORMANCE

Of the original requirements for stability with ±10% mains variations, the 25 kV supply was stable to ∓0·085%, the beam current to ±0·1%, the photomultiplier supply to ±0·01% and these resulted in an indicated X-ray intensity stability of better than ±0·3%.

The absorptiometer is in use for the routine determination of tetraethyl lead in premium grade fuel (1·5 ml./I. gal) and aviation spirit (5·5 ml./I. gal) the reading for any given sample being reproducible to ±0·01 ml./I. gal and ±0·02 ml./I. gal respectively.

In use the absorptiometer is first zeroed on a sample of the actual base petrol without added lead and then the sensitivity set on a standard leaded sample prepared from this base petrol. The concentration of tetraethyl lead in the samples can then be read from a calibration graph.

By this method the effect of impurities and the composition of the base petrol are eliminated since the sample will have the same base as the standards. If no sample of the base petrol is available for standardization, allowance must be made for impurities and composition of the base petrol.(1)

As has been stated, the carbon hydrogen ratio of the petrol will have little effect on the absorption, since, at the working voltage, the absorption coefficients of carbon and hydrogen are about equal. However, density will effect the absorption by a change in density of 0·01 g/cm³ being equivalent to 0·25 ml of tetraethyl lead per Imperial gallon of petrol. With regard to impurities, sulphur is the most usual component and a change in sulphur content of 0·1% is equivalent to about 0·2 ml. of tetraethyl lead per Imperial gallon of petrol.

In routine use, however, standard samples are usually available so the correction for impurities and base petrol composition does not arise.

REFERENCES

(1) Calingaert, G., Lamb, F. W., Miller, H. L., and Noakes, G. E. *Analyt. Chem.*, **22**, p. 1238 (1950).

(2) Marshall, F. H., and Coltman, J. W. *Rev. Sci. Instrum.*, **18**, p. 504 (1947).

(3) Engstrom, R. W. *J. Opt. Soc. Amer.*, **37**, p. 420 (1947).

(4) Crouch, J. W., and Overton, B. R. Mullard Research Report No. 128.

(5) McKenzie, R. B. *Proc. Instn Elect. Engrs* (II), **101**, p. 59 (1954).

A simple monitor circuit for a spectrographic a.c. arc source

By D. F. T. Roberts, B.Sc., A.I.M., M.Inst.W., and E. H. S. van Someren, B.Sc., M.Inst.W., F.Inst.P.,
Murex Welding Processes Ltd., Waltham Cross, Herts.

[*Paper received* 21 *February*, 1956]

An inexpensive unit is described by means of which the form of the discharge voltage and current and the trigger pulses associated with a spectrographic a.c. arc are displayed, and their phasing determined with reasonable accuracy.

The equipment utilizes a 1 in. type 1CP1 miniature self-focusing cathode-ray oscillograph. A 100 c/s time-base locked to mains frequency is used, with adjustable phase-angle marker "pips" to give a convenient display.

A spectrographic source unit was built to give a choice of type of excitation; a rectified and smoothed d.c. arc, a spark at about 12 kV, or an a.c. arc with high-frequency spark ignition. The third type is intended to combine the sensitivity of an arc source with the reproducibility of a spark; a circuit for this purpose is described in B.S. 1225 (1945) and a modified form is outlined in Fig. 1(*a*).

The essential feature is a capacitor C_{22} which receives energy from the mains through R_{78} and is discharged at each half-cycle by a trigger spark of low energy and high voltage from the Tesla transformer T_4. By changing the value of R_{78} and of R_{80}, two tapped resistances controlled by handwheels on the bench, the discharge of the capacitor C_{22} may be varied from sharp pulses to arcs of about 4 ms duration. The phase angle at which the trigger spark discharges C_{22} is controlled by the capacitance C_{29} and resistance R_{82} (either of which may be varied).

The shunt circuit formed by C_{23} and R_{81} is not essential to the a.c. arc, but makes it possible to strike a d.c. arc by switching on the Tesla spark briefly instead of bringing the electrodes into contact. The switches necessary to connect the d.c. arc and simple spark circuits to the same output leads have been left out.

The nature of the a.c. arc discharge is not a function of the circuit alone. The samples which are used as electrodes in the analysis gap also alter the arc characteristics; consequently, it is helpful to have a visual indication of the uniformity of the discharge conditions for different tests; both the phasing of the trigger spark and the wave-form of the discharge pulse are of interest.

It is not easy to produce inexpensive equipment which will indicate these variables using normal moving-coil instruments, as the wave-form and timing of the events are as important as the r.m.s. values associated with them. The present equipment was designed to be sufficiently indicative of wave-form and timing to complete the interpretation given by a simple r.m.s. instrument. Rectification effects are rendered easily visible by the use of a 100 c/s time-base, which also gives a display which makes good use of the circular area available for the trace. The phase angle is indicated by a darkened marker pip on the trace, adjustable to nominal values of 0°, 60°, 80°, 85°, 90°, 95°, 100°, 110° and 150° and the corresponding values on the 180–360° lobe of the a.c. wave.

The requirements set by the attainment of a reasonable accuracy of timing are that the time-base should be well linearized and that the flyback time be relatively brief. As the deflexion voltages of the type 1CP1 tube are unusually small, these requirements are fulfilled by the Newsam time-base used [V_1 and V_2, Fig. 1(*b*)]. The use of a negative feed voltage* prevents the rapid flyback from cutting-off V_1 due

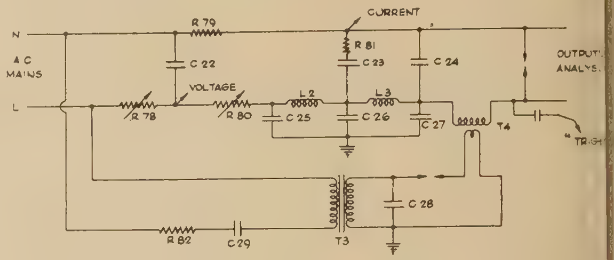


Fig. 1(*a*). See opposite page for legend

to stray capacitance associated with the cathode load. only component of a specialized nature in this unit is feedback condenser C_{13}, which must be a high-quality pa type with a high leakage resistance. The mains squa circuit of V_{5A}, V_{5B} and the differentiator-rectifier V_{4A}, and positive-pulse discharge-drive valve circuit V_3 are of usual design. The use of the coupling from the V_{5A} an to the V_{5B} grid is dictated by the need to exactly synchro the two time-base sweeps in both time and phase with mains a.c. wave-form, which requires precise phasing of negative-going portions of the square waves from V_{5A}, This is most readily obtained by adjusting the mains in resistor R_{77} and the coupling C_{20}, R_{73}, R_{74}. These adj ments are easily made in the unit itself using the oscillosc with the "voltage" Y-input connected directly to the sup mains.

The phase-angle markers require to be stable rather th accurate for the comparative use made in monitoring, so t the adjustment of the phase-splitting resistors R_{32}–R_{4} possible using the type 1CP1 tube itself. The phase-mar is produced by the squaring valve circuit V_6 and differentia rectifier circuit V_7, which feed a negative darkening pulse the oscilloscope grid of about 1½–2½° phase duration 30 V amplitude, any residual positive transients be removed by the germanium diode E_4. The choice of phase angles used was made on the basis of the spect graphic arc unit control required. The width of the mar pulse is adjustable by the alteration of the condenser The pulse is transferred from the positive lobe of the wave to the negative lobe by the input reversing switch S_3

The small deflexion voltages needed permitted the "curre display to be derived from a 2 Ω resistor R_{79} [Fig. 1(*a*)] the earth return lead of the arc, which has no deleteri effect otherwise. The voltage divider R_{53}, R_{54} [Fig. 1(*c*) to reduce the normal input voltage (250 V r.m.s.) to mana able proportions as regards deflexion, and also to per rough assessment of voltage peaks by the use of a fi attenuation ratio.

The display of the trigger pulses is readily made by highly insulated capacitative coupling consisting of a turns (four to eight) of insulated bell wire around the insu

---

* Puckle, O. S. *Time Bases*, p. 133, 2nd Ed. (London: Chapman and Hall Ltd., 1952).

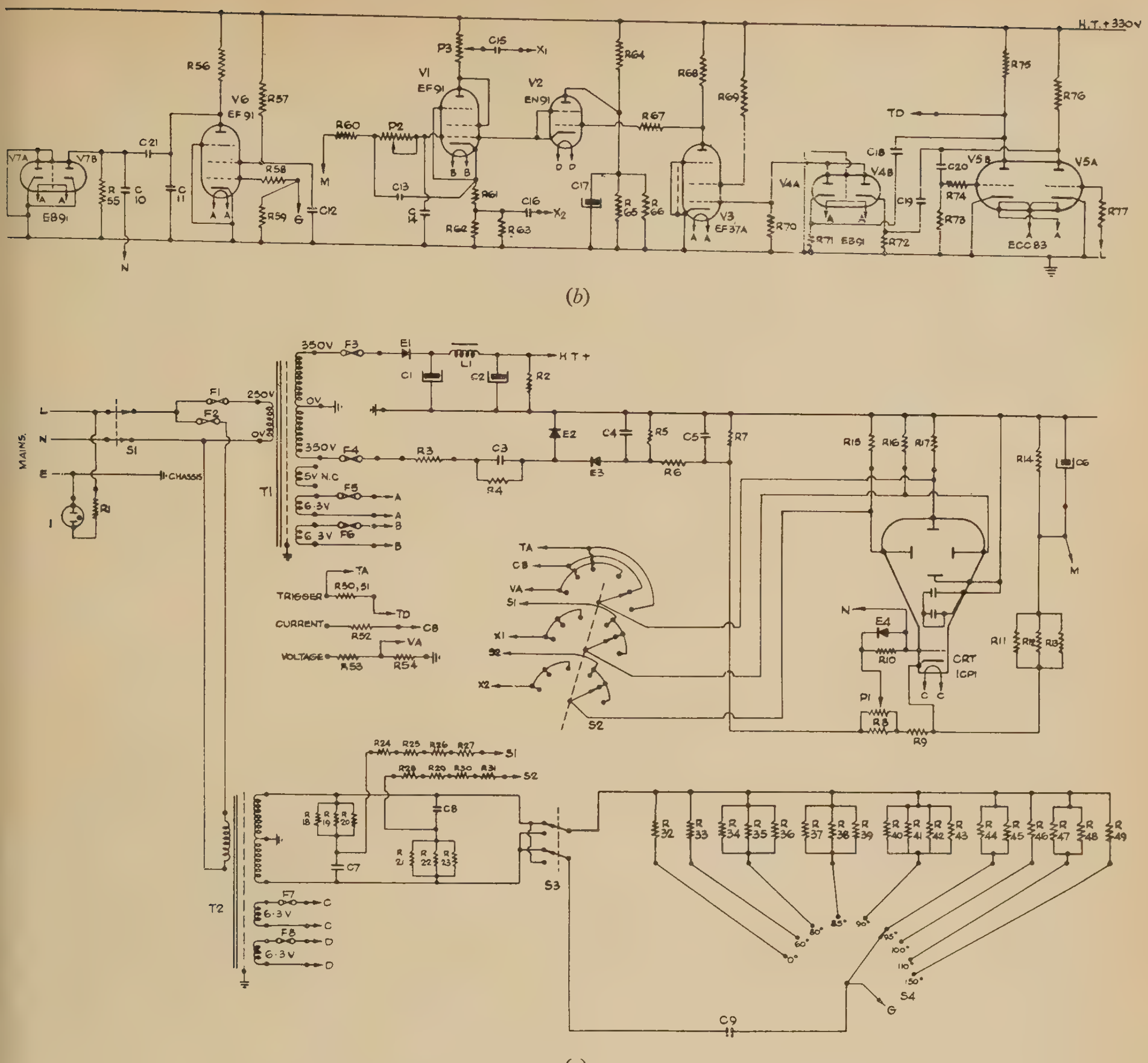

H.T.+330V
R56
V6
EF91
R57
C21
V7A
V7B
EB91
R55
C10
C11
R58
R59
G
C12
M
R60
P2
P3
C15
X1
V1
EF91
V2
EN91
C13
C14
R61
R62
R63
C16
X2
C17
R64
R65
R66
R67
R68
R69
V3
EF37A
R70
V4A
V4B
C18
C19
R71
EB91
R72
TD
C20
V5B
V5A
R74
R73
R75
R76
R77
ECC83
N
(b)
350V
F3
E1
L1
HT+
C1
C2
R2
MAINS
L
N
E
F1
F2
250V
0V
S1
CHASSIS
I
R1
T1
350V
F4
R3
C3
R4
E2
C4
R5
C5
R6
R7
E3
5V N.C
F5
6·3V
6·3V
F6
A
B
R15
R16
R17
R14
C6
M
TA
CB
VA
S1
X1
S2
X2
TRIGGER
R50,51
TD
CURRENT
R52
VOLTAGE
R53
R54
N
E4
R10
CRT
1CP1
P1
R8
R9
C
R11
R12
R13
R24
R25
R26
R27
R28
R29
R30
R31
T2
R18
R19
R20
C8
R21
R22
R23
C7
S3
F7
F8
6·3V
6·3V
C
D
R32
R33
R34
R35
R36
R37
R38
R39
R40
R41
R42
R43
R44
R45
R46
R47
R48
R49
0°
60°
80°
85°
90°
95°
100°
110°
150°
S4
G
C9
(c)

Fig. 1. Monitor circuit for a spectrographic a.c. arc source

(*a*) modified arc circuit; (*b*) timebase and phase-marker circuit; (*c*) power supplies.

All ½ W are high stability)
R_1 = 180 kΩ, ½ W
R_2 = 330 kΩ, ½ W
R_3 = 4·7 kΩ, ½ W
R_4 = 100 kΩ, 2 W
R_5 = 1 MΩ, ½ W
R_6 = 68 kΩ, ½ W
R_7 = 1 MΩ, ½ W
R_8 = 33 kΩ, ½ W
R_9 = 4·7 kΩ, ½ W
R_{10} = 470 kΩ, ½ W
R_{11}–R_{13} = 1 MΩ, ½ W
R_{14} = 100 kΩ, ½ W
R_{15}, R_{16} = 2·2 MΩ, ½ W
R_{17}, R_{18} = 1 MΩ, ½ W
R_{19}, R_{20} = 330 kΩ, ½ W
R_{21} = 1 MΩ, ½ W
R_{22}, R_{23} = 330 kΩ, ½ W
R_{24}–R_{26} = 2·2 MΩ, ½ W
R_{27} = 3·3 MΩ, ½ W
R_{28}–R_{30} = 2·2 MΩ, ½ W
R_{31}, R_{32} = 3·3 MΩ, ½ W
R_{33} = 68 kΩ, 2 W
R_{34} = 180 kΩ, ½ W
R_{35} = 330 kΩ, ½ W
R_{36} = 1 MΩ, ½ W
R_{37}, R_{38} = 330 kΩ, ½ W
R_{39} = 470 kΩ, ½ W
R_{40}, R_{41} = 1 MΩ, ½ W
R_{42} = 470 kΩ, ½ W
R_{43}–R_{45} = 330 kΩ, ½ W
R_{46} = 180 kΩ, ½ W

R_{47} = 2·2 MΩ, ½ W
R_{48} = 330 kΩ, ½ W
R_{49} = 680 kΩ, ½ W
R_{50} = 4·7 MΩ, ½ W
R_{51} = 4·7 MΩ, ½ W
R_{52} = 100 kΩ, ½ W
R_{53} = 470 kΩ, ½ W
R_{54} = 47 kΩ, ½ W
R_{55} = 3·3 kΩ, ½ W
R_{56}, R_{57} = 68 kΩ, 2 W
R_{58} = 1 MΩ, ½ W
R_{59} = 3·3 MΩ, ½ W
R_{60} = 220 kΩ, ½ W
R_{61} = 3·3 kΩ, ½ W
R_{62}, R_{63} = 22 kΩ, ½ W
R_{64} = 47 kΩ, ½ W
R_{65} = 100 kΩ, ½ W
R_{66} = 47 kΩ, ½ W
R_{67} = 4·7 MΩ, ½ W
R_{68}, R_{69} = 100 kΩ, 2 W
R_{70} = 47 kΩ, ½ W
R_{71}, R_{72} = 15 kΩ, ½ W
R_{73} = 3·3 MΩ, ½ W
R_{74} = 1 MΩ, ½ W
R_{75}, R_{76} = 68 kΩ, 2 W
R_{77} = 330 kΩ, ½ W
R_{78} = 100 Ω, 2 kW
R_{79} = 2 Ω, 50 W
R_{80} = 20 Ω, ½ kW
R_{81} = 100 Ω, 250 W
R_{82} = 80 (C_{29}, 20 μf) to 110 Ω (C_{29} zero) } 250 W

P_1 = 1 MΩ linear carbon, 1 W
P_2 = 50 kΩ linear carbon, 1½ W
P_3 = 50 kΩ linear carbon, 1½ W

C_1 = 8 μF, 500 V working electrolytic
C_2 = 32 μF, 500 V working electrolytic
C_3 = 4 μF paper, 500 V working
C_4, C_5 = 4 μF paper, 1000 V working
C_6 = 60 μF, 150 V working electrolytic
C_7–C_9 = 0·02 μF, 500 V working paper
C_{10} = 0·002 μF, 500 V working paper
C_{11} = 0·01 μF, 500 V working paper
C_{12} = 0·25 μF, 500 V working paper
C_{13} = 30 μF, 150 V special paper
C_{14} = 0·05 μF, 500 V working oil-paper
C_{15}, C_{16} = 0·25 μF, 500 V working paper
C_{17} = 30 μF, 150 V working electrolytic
C_{18}, C_{19} = 500 pF, 500 V working mica
C_{20} = 0·1 μF, 500 V working paper
C_{21} = 0·002 μF, 500 V working paper
C_{22} = 50 μF paper, 500 Va.c. working
C_{23} = 4 μF paper, 500 V a.c. working
C_{24}–C_{27} = 0·001 μF ceramic, 5 kV working

C_{28} = 0·005 μF ceramic, 20 kV working
C_{29} = 20 μF or less to zero (switched bank), 500 Va.c. working

V_1 = EF91
V_2 = EN91
V_3 = EF37A
V_4 = EB91 } Mullard
V_5 = ECC83
V_6 = EF91
V_7 = EB91

T_1 = 350–0–350 V, 60 mA
T_2 = 250–0–250 V, 40 mA } all from 250 V, 50 c/s mains
T_3 = 12 kV, 50 mA
T_4 = Tesla coil. Primary 6 turns, secondary 50 turns

L_1 = 25 H, 60 mA
L_2, L_3 = 80 turns air core, 2 in. diameter, 7 in. long, 18 mH

E_1 = Sentercel H18/35/1RW 350 V, 100 mA
E_2 = Sentercel K8/20 400 V, 5 mA
E_3 = Sentercel K8/15 350 V, 5 mA
E_4 = OA61 H.R.V. germanium diode (Mullard)

I = type "G" neon

tion of the Tesla coil output lead. As the trigger pulses on each lobe of the a.c. wave would appear imposed on the same base line, the groups of pulses are separated by feeding the correctly-phased square wave into the deflexion potential from V_{5B}, that is, positive-going a.c. corresponds to the upper trace. The attenuator R_{50}, R_{51} [Fig. 1(*c*)] prevents the trigger pulse amplitude being so great as to cause distortion of the time-base by feeding into the V_{5B} circuit, and attenuates the V_{5B} anode voltage for deflexion purposes.

In order to provide an inexpensive trace expansion in the 80–100° portion only, which is of prime interest, a sine wave X-deflexion is derived from the phase-splitter transformer output. This has the disadvantage of a trace reversal on one lobe, but the marker pips, when in use, prevent confusion.

The unit has been fitted in a 5 in. standard rack panel by using a recently applied type of chasis construction (os scope type XTI36 by Solartron Electronic Instruments I In this the valves are disposed at 45° to the vertical, upwards, and thus the wiring is substantially all on one of the chassis only.

The raw materials for the unit cost £30, includin accessories and nameplates. It has been in use for s time without a fault appearing.

ACKNOWLEDGEMENTS

The authors wish to thank the Directors of Murex We Processes Ltd. for permission to publish this note. Th are also due to Mr. D. W. Ransome for diligent enthusiastic work in the construction of the unit.

A semi-automatic pen-recorder chart analyser

By C. W. Spencer, B.Sc., and G. H. Bazzard, B.Sc., Radio Research Station, Slough, Bucks.

[*Paper received* 3 *February*, 1956]

A description is given of an instrument which enables a rapid analysis of the variations of displacement of a pen trace upon a moving chart to be made. The pen trace is followed manually by means of a cursor making an electrical connexion with a number of fixed contacts, which are in turn connected through a distribution board to electrically-operated counters. A cam-operated make-and-break switch produces the pulses to actuate any particular counter, determined by the position of the movable contact. The numbers of pulses recorded on the counters are measures of the amounts of time the pen displacement is between pre-selected levels across the chart.

In order to determine the statistical distribution with respect to time of a quantity which has a range of possible values, it is necessary to be able to obtain the frequencies of occurrence of a number of fixed values within that range. The instrument described in this paper was developed as an aid in the computation of such frequencies for a quantity which is recorded upon a suitable chart. For example, the instrument may be applied to the analysis of the field strength variations at a receiving site, the variations having been recorded by a pen trace on a moving paper chart.

The instrument consists essentially of a number of electrically-operated counters connected through a multi-contact switch to a simple pulse generator. The position of the contact arm of the switch is manually adjusted to follow the variations of the pen trace, so that the counters record numbers which are proportional to the time the trace is between certain pre-selected levels. These levels may be varied according to the particular requirements of the analysis, i.e. they may be selected to conform to any calibration of the displacement of the pen trace across the chart.

DESCRIPTION

The chart is drawn over a 6 in. diameter drum against which it is held by spring-loaded rubber rollers, the drum being driven by an electric motor. This mechanism is contained within a metal box which has three hinged sides to provide easy accessibility for changing the spools, etc. On the top of the box and directly over the drum is a Perspex window through which the chart may be observed as it is carried round by the drum. A sliding cursor is mounted in the window in such a way that it can be moved at right angles to the movement of the chart. In operation the curs adjusted manually so that its fiducial mark is always dir above the pen trace on the chart.

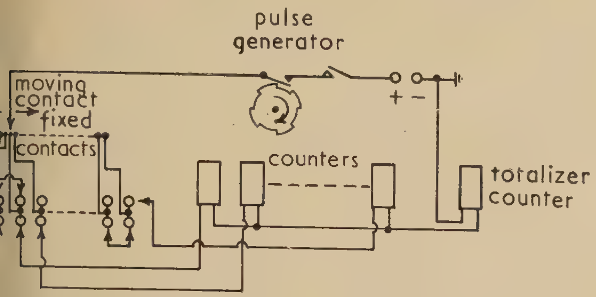
The cursor carries the moving contact of the multi-co switch; the position of this contact is therefore related t displacement of the pen trace across the chart. The mo contact itself consists of a simple tapered tubular moun carrying a spring-loaded steel ball. The contact area of ball is ground flat to such an extent that it just bridges gap between adjacent fixed contacts.

The bank of fixed contacts is made up of a nun (approximately 130) of 1 × ½ in. strips of $\frac{1}{64}$ in. phosp bronze separated by insulating material of the same dir sions, the whole being rigidly clamped together in a Kera holder. The final machining of the fixed contacts was c after assembly to produce a smooth, flat surface. E fixed contact is connected to separate pairs of plug soc on a distribution board mounted on one side of the Any number of the fixed contacts may be connected toget using links between the sockets, and subsequently conne to one of the counters. In this way a particular counter be made to correspond to any required interval across chart.

The four-figure non-resetting counters, requiring al 40 V d.c. to operate them, are a standard Post Office t There are twenty counters in the analyser, so that the va tions of the pen displacement may be separated into tw different levels if required.

A six-figure reset counter is provided to count the t number of pulses generated during the analysis of a partic section of chart and is used as a check against the total of individual counters.

e pulses necessary to operate the counters are generated simple make-and-break switch operated by a cam on lrum shaft. In this way the number of pulses generated second is directly related to the speed of the chart under cursor, and variations of the speed of the driving motor ot affect the result of an analysis. A pulse rate of about er second with a chart speed of about 1 in. in five seconds itable for the particular records for which the analyser developed, but these figures could be varied to suit individual requirements, subject to not exceeding the imum counting rate of the counters used and to being to follow the pen trace displacements with the cursor.



ig. 1. Diagram illustrating the electrical circuits of the analyser

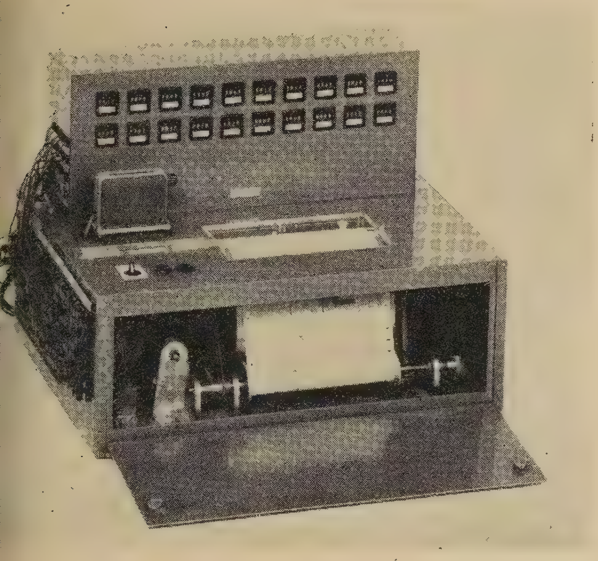


Fig. 2. General view of the analyser

parate switch is provided in series with the cam-operated ch so that the pulses may be stopped if necessary, e.g. n a break in the record appears on the chart.

schematic diagram of the electrical connexions is given ig. 1, indicating the manner in which a particular counter be connected to any desired number of fixed contacts on switch *via* the distribution board.

Fig. 2 gives a general view of the analyser with a chart in position ready for examination. An example of the type of recording which may readily be analysed is shown in Fig. 3. This is, in fact, a recording of radio field strength at a frequency of 48 Mc/s as observed at a distance of 155 miles from the transmitter. The ordinate is shown as the field strength in decibels relative to 1 μV/metre, the nature of the scale being determined by the performance of the receiver. Fig. 4 shows the result of using the instrument described to analyse this portion of record: it is drawn on arithmetic probability paper, and since the field strength is plotted in logarithmic units, it may be concluded that the field strength amplitude distribution with respect to time is "log-normal."

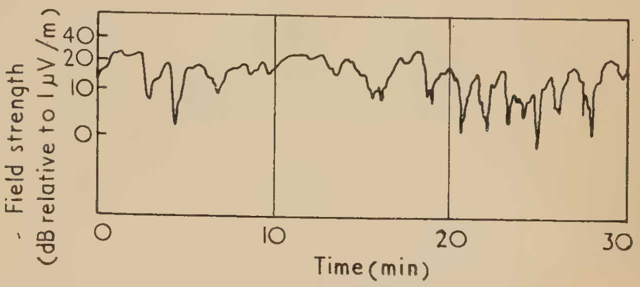


Fig. 3. Section of a typical record

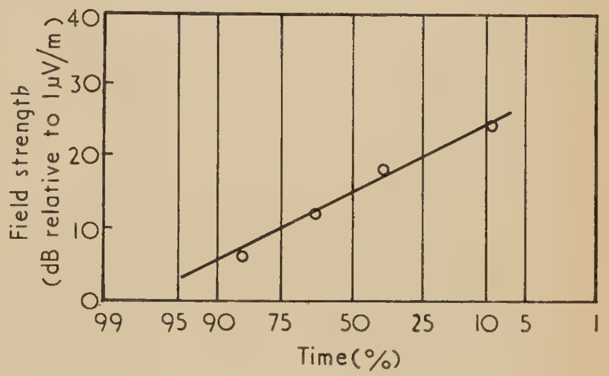


Fig. 4. Distribution curve in which abscissa represents percentage of time the field strength equals or exceeds ordinate value

It should be stressed that the instrument may be used for the analysis of any quantity whose variations can be presented in a similar manner, and it is not necessary for the independent variable to be time.

ACKNOWLEDGEMENTS

The work described above was carried out as part of the programme of the Radio Research Board. The paper is published by permission of the Director of Radio Research of the Department of Scientific and Industrial Research.

A calorimetric method of determining the energy output of radioactive materials

By A. G. White, B.Sc., Ph.D., Chemistry Division, Atomic Energy Research Establishment, Harwell, Berks.

[*Paper first received* 29 *December*, 1955, *and in final form* 8 *February*, 1956]

A method of making a direct measurement of the rate of change of temperature with time is described. To do this a large capacity condenser and galvanometer are used in a circuit containing a thermistor as the temperature sensitive element. A description of two calorimeters embodying this principle, with which the energy outputs of radioactive samples may be determined, is given. The theoretical basis of the method is examined and means of estimating correction terms are suggested.

Measurements of the energy emission of radioactive materials by calorimetric methods have usually depended on a determination of the temperature rise produced in a calorimeter by the sample, after allowing sufficient time for thermal equilibrium to be established. It is assumed that Newton's law applies, that is, the rate of change of calorimeter temperature follows equation (1)

$$\dot{\theta} = (L/c)(\theta - \theta_s) + (W/c) \qquad (1)$$

where $\dot{\theta} = d\theta/dt$, θ = calorimeter temperature at time t, θ_s = temperature of surroundings, L = thermal leakage modulus of calorimeter in watts/°C, W = heat input from sample in watts, and c = heat capacity of calorimeter in joules/°C.

If θ_s is maintained constant, equation (1) can be integrated to

$$\theta = \theta_s + (W/L) - [\theta_c - \theta_s - (W/L)] \exp(-Lt/c)$$

θ_c being the value of θ when $t = 0$. When t is large this reduces to

$$\theta = \theta_s + (W/L)$$

so that

$$W = (\theta - \theta_s)L$$

However, if the measurements are to be made precise then $(\theta - \theta_s)$ must be made as large as possible and hence L must be kept small. A small value of L necessarily implies that attainment of equilibrium will be a slow process, and for work of this type twenty-four to forty-eight hours is commonly required.

If the value of the rate $\dot{\theta}$ could be directly measured then, the other quantities in equation (1) being known, it would be possible to calculate W from a single measurement, occupying a short time only, and without the necessity of awaiting the attainment of equilibrium.

DESCRIPTION OF THE METHOD

There exists a very simple experimental method by which this rate may be directly measured, which appears to have been previously overlooked. If, in Fig. 1, R_T is a resistance thermometer and R a fixed resistance then the volta developed across R_T will vary with temperature and h if the temperature of R_T is changing, with time. sequently, if a galvanometer G and condenser C are a to the circuit, as in Fig. 2, then current will only flow thr the galvanometer when the voltage E is changing, i.e. the temperature, θ, of R_T is changing. The magnitude o current will be given by the expression

$$i = C\dot{E}$$

where C is the capacity of the condenser and $\dot{E} = d$ and if $\dot{E} = A\dot{\theta}$ then

$$i = CA\dot{\theta}$$

where A is a constant. So that the current through galvanometer is directly proportional to the required In what follows CA will be written as B to avoid confus

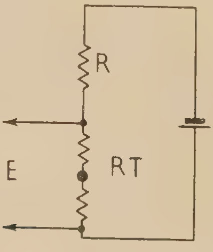


Fig. 1.

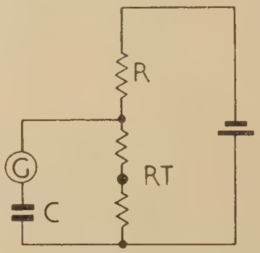


Fig. 2. Circuit used with first calorimeter

If R_T is inserted in a calorimeter, the power output radioactive sample may be determined from two or t galvanometer readings. The galvanometer reading wit the sample in the calorimeter is first noted, the sample ins and the new value determined. The values of these rea will be given by

$$(i_1/B) = \dot{\theta}_1 = -(L/c)(\theta_1 - \theta_s)$$

and

$$i_2/B = \dot{\theta}_2 = [W - L(\theta_2 - \theta_s)]/c + \delta c)$$

where i_1 and i_2 are the current readings before and introduction of the sample respectively, θ_1 and θ_2 are calorimeter temperatures at the times at which i_1 and i_2 observed, and δc is the thermal capacity of the sar

$$\text{Hence} \quad \frac{i_2 - i_1}{B} = \frac{W}{c + \delta c} + \frac{L}{c}\left[\frac{(\theta_1 - \theta_2)c + (\theta_1 - \theta_s)\delta c}{(c + \delta c)}\right]$$

If i_2 is observed for several minutes and then extrapol back to the time when the last observation of i_1 was m and at which the sample was introduced, then, assu

: are no discontinuities in the temperature/time curve, $= \theta_1$ and equation (6) simplifies to

$$\frac{i_2 - i_1}{B} = \frac{W}{c + \delta c} + \frac{L\,(\theta_1 - \theta_s)\delta c}{c\ \ (c + \delta c)} \qquad (7)$$

ıe second term on the right-hand side of this expression, :h will be discussed later, is normally a small correction ı so that to a first approximation

$$(i_2 - i_1)/B = W/(c + \delta c) \qquad (8)$$

ı which W is readily determined if c and δc are known. value of $(c + \delta c)$ may be obtained by electrical heating he calorimeter at a known rate, W_e, with the sample still lace. Under these conditions the new current reading i_3 ven by

$$\frac{i_3}{B} = \dot{\theta}_3 = \frac{(W + W_e) - L(\theta_3 - \theta_s)}{(c + \delta c)}$$

i_3 is observed for several minutes and extrapolated back ıe time at which electrical heating was commenced then $= \theta_2'$ and

$$(i_3 - i_2')/B = W_e/(c + \delta c) \qquad (9)$$

re θ_2' and i_2' are the values of θ_2 and i_2 at this particular . From equation (9), W_e being known, $c + \delta c$ can be ılated or, alternatively, use may be made of the relation

$$W/W_e = (i_2 - i_1)/(i_3 - i_2') \qquad (10)$$

is also possible to prepare a calibration curve, showing relation between $(i_2 - i_1)$ and W, by inserting in the rimeter a dummy sample which has approximately the : thermal capacity as the samples to be investigated, and ing the calorimeter electrically at known rates.

practice if small power inputs are to be measured then ust be very large, at least 1000 μF, and it is necessary to ʒn for as large a value of $\dot{E}$ as possible. For this purpose very high temperature coefficient of resistance of mistors makes them particularly suitable for use as R_T. vever, this introduces the complication that the resistance- perature relationship for thermistors is exponential so $\dot{E} \neq A\dot{\theta}$. Over limited temperature ranges the departure ı linearity is small and to a first approximation may be ɪred. If necessary the resistance/temperature relationship be made linear either by the correct choice of R, according he method of Beakley,⁽¹⁾ or by shunting the thermistor ı a suitable fixed resistor.⁽²⁾ It will be seen later that in two instruments so far constructed this has not been ıd to be necessary.

hroughout the above discussion it has been assumed that ın be treated as constant. As only ten to twenty minutes required for a determination it is reasonable to assume the condition will be met without the necessity of provid- a thermostat, and the instruments described later have, ıct, been operated on a laboratory bench. In instruments higher sensitivity or greater precision a thermostat may ɔme necessary.

FIRST CALORIMETER

he first calorimeter constructed embodying the foregoing s consisted of an aluminium block contained in a Dewar el and is shown in Fig. 3. The circuit of Fig. 2 was used, eing 8·2 kΩ and R_T a thermistor type A1451/100 (by ıdard Telephones and Cables Ltd.), with a nominal tance of 10 kΩ at 20° C. A potential of 3 V was applied the galvanometer used had a sensitivity of 300 mm/μA at 1 m. It was found necessary to provide a total capacity of 4000 μF in order to achieve sufficient sensitivity to determine energy outputs from 10 to 100 mW, and a major practical difficulty was to obtain condensers possessing a low enough leakage current. Eventually four 1000 μF condensers, rated for 12 V working, were selected from a batch of two dozen by individual testing, each being left connected to a galvanometer and 1·5 V supply overnight, and those showing the lowest leakage current chosen. In this way the total leakage current in the instrument was kept down to 0·1 μA. This relatively high leakage current precluded the use of a more sensitive galvanometer and also made any appreciable increase in capacity of little value, owing to the accompanying increase in standing current. It was found necessary to switch the battery on twenty-four hours before using the instrument in order to ensure that the condensers were fully charged. A shorting switch was provided to protect the galvanometer. With this system a linear relationship between power input to the calorimeter heater and change in galvanometer deflexion was obtained, and is shown in Fig. 4, indicating that the

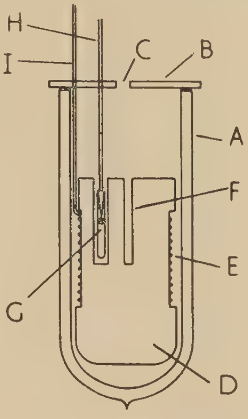


Fig. 3. First calorimeter

A, Dewar vessel; *B*, Perspex lid; *C*, hole for introduction of sample; *D*, aluminium block 2 in. × 1 in. diameter; *E*, heater winding; *F*, sample well; *G*, thermistor; *H*, thermistor leads; *I*, heater leads.

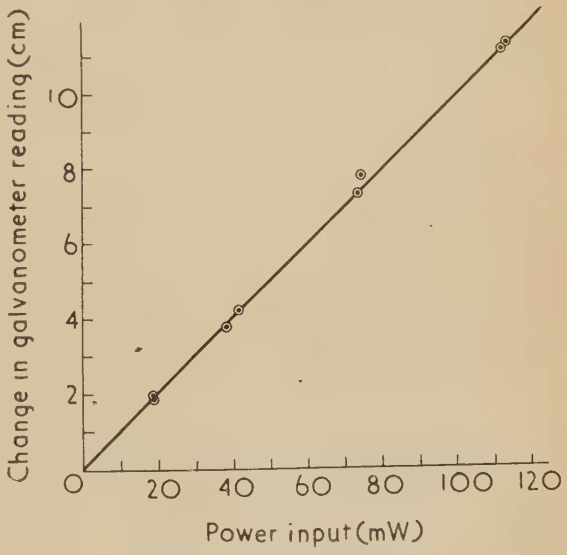


Fig. 4. Calibration curve for first calorimeter

non-linear resistance/temperature relationship of the thermistor was not a source of error. As the instrument was intended for the determination of ^{210}Po in X-ray capillaries the thermal capacity of the sample and its container could, in this case, be safely neglected in comparison with the thermal capacity of the calorimeter which was about 33·5 J/°C.

SECOND CALORIMETER

As the results obtained with the first calorimeter clearly indicated that the method was a practicable one, a second calorimeter was designed to cover the range of energy outputs up to 500 mW, once again being intended for use in estimating ^{210}Po. Two important changes were made in the circuit, which is shown in Fig. 5. The first was the use of two thermistors in a bridge network which both doubled the sensitivity of the system for a given applied potential, and, owing to the much lower value of the output voltage E, reduced the leakage current flowing through the condensers. The second change was the use of tantalum electrolytic condensers to provide the large capacity needed, these have a leakage current which is very much lower than that of ordinary electrolytic condensers and, in fact, the combination used, totalling 1100 μF, gave a leakage current of less than 4×10^{-3} μA even with 3 V applied. Further, only some three to four hours was required to charge the condensers. This very substantial improvement permitted the use of a much more sensitive galvanometer (4500 mm/μA at 1 m). From the stability of the circuit and the steadiness of the galvanometer readings there appears to be no reason why the capacity should not be very substantially increased if necessary. To avoid galvanometer tangent error a curved scale was used.

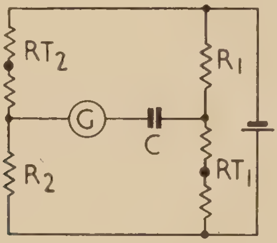


Fig. 5. Circuit used with second calorimeter

R_1, $R_2 = 10\,000\,\Omega$. RT_1 RT_2 = S.T.C. thermistors type A1451/100.

The calorimeter itself was made from a block of pure aluminium and is shown in Fig. 6; it was mounted on Perspex spacers in a thin, polished, copper shield and the whole was contained in a Perspex box. The mass of the finished calorimeter was 350 g, giving a thermal capacity of 314 J/°C. A measurement of the leakage modulus gave a value of $L = 0{\cdot}026$ W/°C. An electrical heater wound in the helical groove on the outside of the block consisted of 50 Ω of 30 s.w.g. manganin wire and was cemented in place with Bakelite varnish. The sample well (see Fig. 6) was closed by a sliding cover to prevent convection losses, and thin copper sample holders, also shown in Fig. 6, were provided for the samples contained in sealed glass tubes which made a close fit in the holders. Two wells were also provided to contain the thermistors.

As a check on the veracity of the results, a "dummy sample" was made from a length of glass tubing on which was wound a heating coil, again of 50 Ω of 38 s.w.g. manganin wire, the whole being enclosed in one of the sample holders, the current-carrying leads being brought out through holes drilled in the lid. With this "dummy sample" inserted in the sample results obtained by heating the two windings were com and found to be identical. This is shown in Fig. 7, also shows the effect of increasing the bridge supply vo The relationship between deflexion and power input was

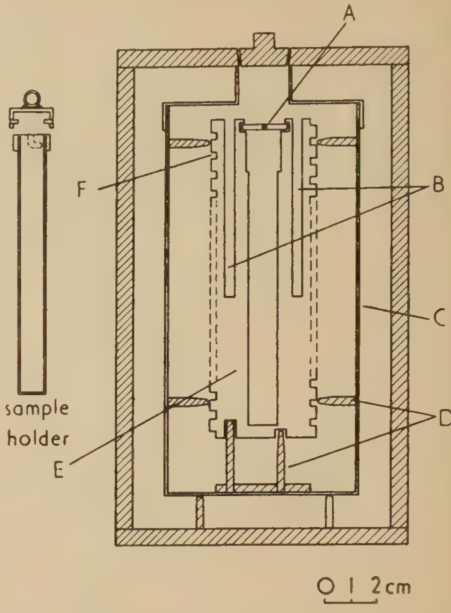


Fig. 6. Second calorimeter

A, sliding cover to sample well; *B*, holes for thermis *C*, copper shield polished both sides; *D*, Perspex; *E*, cal meter block of pure aluminium; *F*, helical groove for h winding.

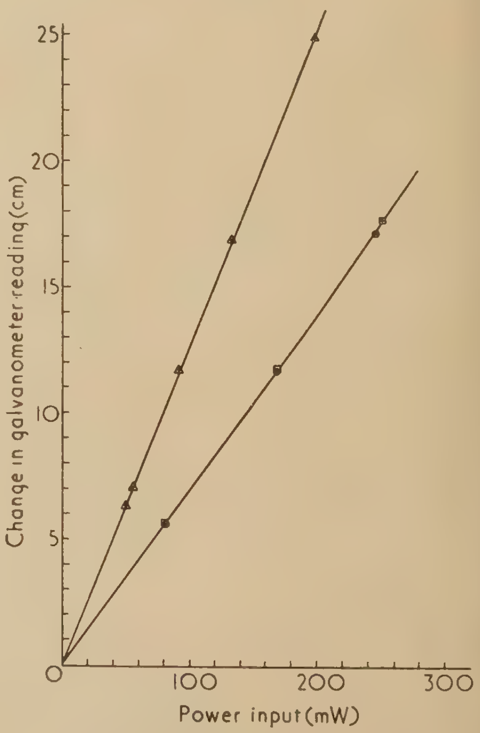
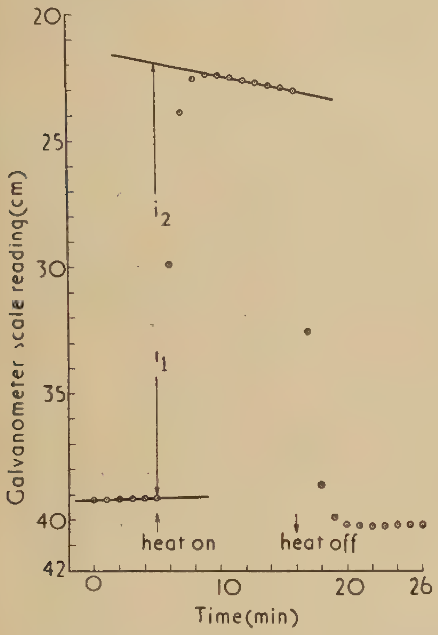


Fig. 7. Calibration curves for second calorimeter

△ = power input from heater, bridge supply 9 V.
⊙ = power input from dummy sample, bridge supply 4·5
⊡ = power input from heater, bridge supply 4·5 V.

linear, showing that no undesirable effects had been uced by assuming a linear R/θ characteristic for the nistors. Typical experimental data from which points as those of Fig. 7 were obtained are shown in Fig. 8, hich the steady decrease in galvanometer reading after naximum is reached, due to increase of θ_2, is clearly seen. e further effect which should be mentioned is the large ient change in galvanometer reading which occurs when dioactive sample is inserted in the calorimeter. The le and its container, which possess a relatively small nal capacity, are held considerably above room tempera- by the energy output of the sample. Consequently, when ample is placed in the calorimeter $\dot{\theta}$ will rapidly increase then decrease, producing a sharp peak in the plot of anometer reading against time, until the sample and imeter temperatures have become equal. After this it follow the same course as is observed with electrical ing and illustrated in Fig. 8.



ig. 8. Typical experimental results of calorimetric method. Power input 248 mW from dummy sample

THE CORRECTION TERM

o far the errors introduced by neglecting the second term quation (6) have not been considered. If the method of apolating the readings back to the point at which the ple was introduced, or heat supplied, is followed then ation (7) may be used and the point at issue becomes the tive magnitude of W and $(L/c)\,(\theta_1 - \theta_s)\delta c$. It is at once lent that in designing the calorimeter good thermal lation, leading to a low value of L, should be aimed at, , as far as possible, the thermal capacity of the sample its container, δc, should be kept small in relation to the rmal capacity of the calorimeter. In the second calori- er described above L was 0·026 W/°C and $\delta c \simeq 8{\cdot}4$ J/°C that $L\delta c/c$ was 0·0007 W/°C; consequently, as long as $- \theta_s)$ was not greater than 1° C, then values of W down 0 mW could be determined with an error from this cause greater than 1%, while for larger values of W the error uld be proportionately less. In practice, θ_1 might rise re than 1° C above the temperature of the surroundings if samples of high power output were kept in the calorimeter for some time during previous determinations; hence, it would be undesirable to attempt to estimate small power outputs immediately after several large samples had been used. Further, if small samples are estimated first, then the increase in θ_1 will be much less than 1° C, e.g. a 70 mW sample will raise θ_1 approximately 0·13° C in 10 min, which is an adequate time for the estimation, so that in fact the 1% error will extend down to very much lower levels than 70 mW.

If an attempt is made to calculate the correction term the only difficulty which arises is a determination of $(\theta_1 - \theta_s)$, as $(c + \delta c)$ can be measured as described previously, using equation (9), and c and L, which are constant for a particular calorimeter, may be measured quite easily in independent experiments. The present calorimeter is not designed to permit an actual determination of $(\theta_1 - \theta_s)$ as the accuracy required in the measurements did not warrant it, but this could readily be provided for by inserting one junction of a thermocouple in a suitable well in the calorimeter while fixing the other junction to the copper shield of Fig. 6; the output could then be read on a subsidiary galvanometer and would give a direct measure of the quantity required.

It is also possible to estimate $(\theta_1 - \theta_s)$, although rather crudely, by making certain extra observations during an experiment. After the energy output from a sample has been measured, the sample is removed from the calorimeter and the galvanometer deflexion is noted for several minutes until is has become fairly steady again. Then, before the sample is introduced,

$$i_1/B = \dot{\theta}_1 = -\,(L/c)\,(\theta_1 - \theta_s)$$

at some time after removal of the sample

$$i_x/B = \dot{\theta}_x = -\,(L/c)\,(\theta_x - \theta_s)$$

then putting

$$\rho = i_1/i_x \quad \text{and} \quad \Delta = (i_1 - i_x)/B$$
$$(\theta_1 - \theta_s) = c\Delta/[L(1 - \rho)] \tag{11}$$

If this method is to be used it is important to remember that the observed galvanometer readings giving $\dot{\theta}_1$ and $\dot{\theta}_x$ also contain a component due to the leakage current through the condensers which must be previously determined and subtracted.

In any attempt to use the method for measurement of very small power outputs, one other point should be borne in mind. This is the fact that the power dissipated by the thermistors inevitably means that $(\theta_1 - \theta_s)$ cannot be made zero as the calorimeter temperature must always be slightly higher than that of its surroundings. Hence, any attempt to increase the sensitivity by increasing the voltage applied to the bridge will at the same time increase the contribution to $(\theta_1 - \theta_s)$ due to this cause, and hence make the correction term larger. The most satisfactory way to achieve greater sensitivity would be to increase the capacity C and the sensitivity of the galvanometer. If a sufficient increase can be obtained the voltage applied to the bridge could then be reduced, thus reducing the contribution to $(\theta_1 - \theta_s)$ of the power dissipated in the measuring circuit.

CONCLUSION

While it is not suggested that the method described in this paper is at present a satisfactory alternative to the twin calorimeter method for high precision determinations of the energy of radioactive decay, it does offer certain advantages for work where an accuracy of the order of 1–2% will suffice. These are (*a*) very simple equipment is used, and owing to the short time required for a determination, a thermostat is unnecessary; (*b*) the time required for a determination is reduced to a few minutes instead of many hours.

It is obvious that the method is most satisfactory when used for determining materials of high specific activity, such as ^{210}Po, for which it was devised, where the thermal capacity of the sample can be made small in comparison with that of the calorimeter. However, provided that some provision is made for the assessment of the correction term, there appears to be no reason why materials of lower specific act which for a given power output will possess a larger th capacity, should not be used or why higher precision sh not be achieved.

REFERENCES

(1) Beakley, W. R. *J. Sci. Instrum.*, **28**, p. 176 (1951).
(2) *The Use and Application of Thermistors*, Technical p cation ISD/TH2 (Standard Telephones and C Ltd.).

A general purpose electromagnet

By W. Sucksmith, F.Inst.P., F.R.S., and S. P. Anderson, University of Sheffield

[*Paper received* 18 *January*, 1956]

A general purpose 10 cm pole diameter laboratory electromagnet is described. Particular attention is given to the magnetic and electrical circuits, and to those features of construction which are thought to be most important.

During the last thirty years one of us (W. S.) has been engaged on various magnetic measurements and many electromagnets have been constructed for these investigations. A magnet of 10 cm pole diameter has met most requirements, and the design described below is the result of considerable experience. It has been used chiefly in saturation intensity measurements on ferromagnetics and susceptibility determinations on paramagnetic materials. The authors have felt that it would be profitable to publish the main features of construction of the electromagnet together with its performance. These are contained in the account which follows.

CONSTRUCTIONAL MATERIAL

The magnetic circuit. This consists of three parts, the U-shaped yoke *AA*, the pole tips *BB* (Fig. 1), and the pole pieces *FF* (Fig. 2). The yoke material is largely determined by the permissible residual field. If this must be reduced to an absolute minimum, an iron forging as nearly pure as can be obtained, and carefully annealed, is essential. In this minimum remanence and the highest saturation intensity be achieved. The actual permeability is of secon importance since the reluctance of the working air-gap is main feature in controlling the field at low excitation. reluctance also reduces the remanent field in the gap low value. Should such a low residual field not be essen then more freedom of choice is allowed in the selectio the material of the yoke. A low carbon steel, i.e. aro 0·07% carbon, annealed so that it is as magnetically "s as possible is reasonably satisfactory, and with care in selection of the rest of the magnetic circuit, residual field low as 50–100 oersteds are obtained. With care exercise the technique of switching off the exciting current, this be kept low and also reasonably constant. It will be real that the importance of the residual field depends upon type of measurement envisaged. Thus in measurement the approach to saturation of soft ferromagnetics, a h residual field would be intolerable, whereas in susceptibi determinations, the effect of even a high residual field usually unimportant. Should field conditions be not exact then more liberty of choice is possible, and a higher carb content is permissible.

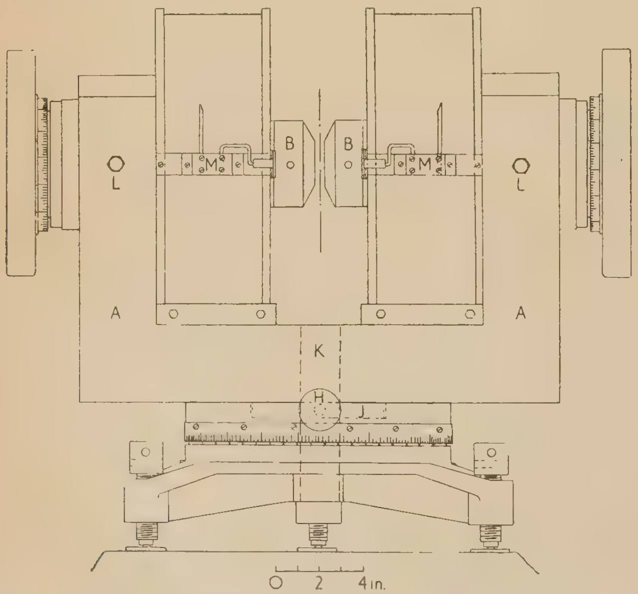


Fig. 1. Complete assembly of electromagnet

As one approaches the pole gap, the choice of mate becomes more important, and forged iron rod is required both pole pieces and pole tips. For ordinary requireme the same material will serve for both purposes, but appearance of faults and inclusions in or near the surface the pole-tip faces can influence the uniformity considerab So important is this in some cases that it has been fou necessary to make "inserts" of specially selected high gra iron to form the parts within 1 to 2 cm of the working g For cylindrical or truncated conical poles, the field should a minimum at the middle of the pole axis, and a maximum this point in any perpendicular direction. This condition not be achieved with faulty material.

The magnetizing coils. The first coils were of No. 12 s.w (2·64 mm) cotton-covered wire, the plane faces being wat cooled, and currents up to 20 A being used. This means cooling was found to be ineffective other than in the immedia neighbourhood of the water jackets, and it was found w worthwhile to dispense with these and to lower the maximu current to 13–14 A, scaling up the number of turns *per lay* ortionally so as to maintain the same ampere-turns and ide diameter. At the same time the cotton-covered wire, hich the early stages of carbonization set in at little more 100° C, was replaced by enamelled wire which is con- ably more resistant to heat. (On one or two occasions lectromagnet has been accidentally left with the current ing for some hours without any apparent damage.) wire will also withstand less careful treatment during ling. In the opinion of the authors, the additional culties involved in the use of asbestos or glass covering not worthwhile.

e cylindrical cores of the coils are made of cast bronze unmetal, thus ensuring higher mechanical strength and ter freedom from blow holes, whilst the end plates are of d sheet brass (Fig. 3).

emainder of assembly. Nearly all the remaining ancillary s are of ordinary cast iron, the chief exceptions being the s on the pole-piece adjustment and on the turntable, h are of brass (Fig. 1).

CONSTRUCTION

e yoke and pole assembly. The machining of the yoke ite straightforward. First the base is machined flat and es as a general reference plane. The two arms of the U e yoke must be machined smooth on the inside, so as to it close approach of the coils, and on at least a portion e outside, to allow accurate fitting of the arrangement for rol of the pole-gap assembly. The axis of the 100 mm eter holes for the pole pieces must be carefully alined llel with the base. The spigot hole *K* in the base is about . diameter.

he poles and pole tips are machined from the forged soft rod and the suitable length of square section thread ut five turns to the inch) cut on the pole piece (see Fig. 2). initial size should not be less than $4\frac{1}{4}$ in., and a sufficient th should be acquired not only for the pole pieces but for a variety of pairs of pole tips. A keyway runs llel to the axis of the pole piece. This is secured by the s *LL* (Fig. 1) such that during translation of the pole e no rotation takes place.

he pole tips are attached to the pole pieces by turning n a portion of the tips to approximately 1 in. diameter threading to screw into tapped holes in the pole pieces. It great importance to ensure that there is a minimum of air space at the bottom of the tapped hole if uniformity of field and field gradient are required.

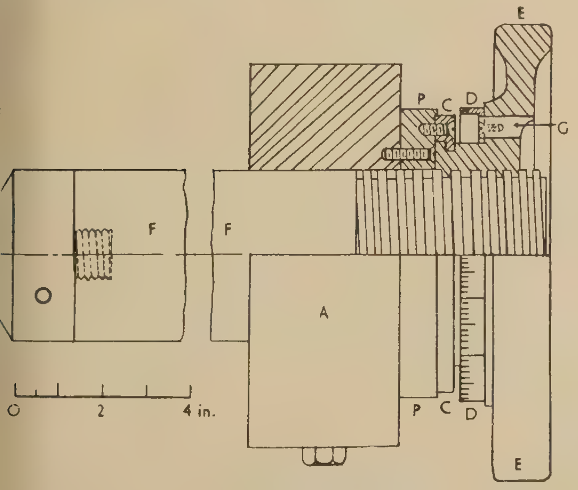


Fig. 2. Pole-gap adjustment

The pole-gap adjustment is illustrated in Fig. 2. First of all the pole piece *FF* is carefully turned to fit the 100 mm hole in the yoke. With this in position the cast iron ring *PP* is fitted to the yoke by six countersunk head steel screws. The handwheel *EE* already machined and threaded, and with the scale *DD* in position, is then screwed on the pole piece. Finally the two phosphor bronze semi-circular retaining rings *CC* are fixed into position, each using four holding screws, which are inserted through the hole *G* in the handwheel.

The coil formers. The cast bronze or gunmetal core *AA* (Fig. 3), turned to internal diameter of 4 in., and external diameter of $4\frac{7}{8}$ in., is threaded to take the end plates *BB* which are of $\frac{1}{4}$ in. sheet brass, 14 in. diameter. Sheets of Paxolin *CC*, $\frac{1}{16}$ in. thick and identical in size with the end plates, are gripped between the core and plates, whilst the cylindrical surface of the core is covered with a strip of similar insulating material *DD* $\frac{1}{32}$ in. thick and long enough to give slightly more than two complete thicknesses.

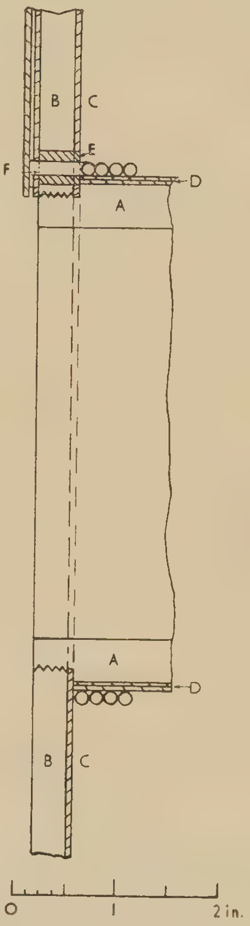


Fig. 3. Section of coil former

The winding of the coils. A screw-cutting lathe is used for this, and Fig. 3 illustrates the beginning of the winding. The inner end of the winding is brought through an ebonite bush *E*, and soft-soldered into a hole in a copper strip *F*, $\frac{1}{2}$ in. by $\frac{1}{32}$ in., which runs up the outside of the bobbin between two Paxolin strips screwed to the end plate. During the winding of the coil it is important to ensure uniform packing for each layer. On completion of a layer, the gap where the wire leads on to the next layer must be packed with pitch or bitumen and smoothed down before the next layer is commenced. This is essential as departures from uniformity are cumulative. Care must be taken to avoid damage to the enamel insulation, but the authors have found the protection of oiled silk useful at doubtful spots in the wire. Joining the wire presents little difficulty, the method being to half-lap the ends, and then hard solder them. The joint is filed down and then lacquered with a strip of oiled silk wrapped around the joint and trapped between neighbouring turns to complete the insulation. Any increase in the number of turns per layer must be avoided, as it is easy to force the end plates outwards. After binding the last layer with insulating material, the ends of the windings are anchored to a terminal block *M* (Fig. 1), which bridges the two end plates of the coil.

Typical data for a coil are as follows: turns, 1850; layers, 45; turns per layer, 41; weight of wire, 155 lb; resistance, 4·4 Ω.

Rest of assembly. The completed magnet sits on a circular turntable free to rotate through 360° and can be locked in any position. This clamping screw *H* (Fig. 1) binds on to the clamp disk *J* which is shrunk on to the central spigot *K*.

The circular table is attached to the tri-leg base through the spigot, and rotates on a self-contained crowded ball race of 11 in. mean diameter carrying about sixty-seven $\frac{1}{2}$ in. steel balls in a $\frac{9}{32}$ in. radius circular groove.

Performance. The table gives specimen field values for 10 cm diameter pole tips tapered at a semi-angle of 60°, and truncated to 2 cm pole-face diameter for different pole gaps. The exciting current is supplied from a 128 V storage bat

For protection against insulation breakdown due to induced electromotive force at break, a 200 V, 100 W is permanently connected across each coil.

Table showing variation of field in centre of gap with excit and gap length

Field current (A) \ Pole gap (cm)	1·5	2·0	2·5	3·0	3·5
2·0	5 900	4 300	3 700	2 800	2 40
3·0	8 700	6 500	5 200	4 300	3 70
4·0	11 600	8 700	7 100	5 600	4 80
5·0	14 100	10 500	8 900	7 300	6 10
6·0	15 200	11 900	9 900	8 400	7 30
7·0	16 800	13 400	11 100	9 300	8 10
8·0	17 800	14 000	11 900	10 200	8 70
9·0	18 500	14 700	12 600	10 600	9 4
10·0	18 900	15 300	13 100	11 300	9 9
11·0	19 400	16 000	13 600	11 700	10 30
12·0	19 800	16 400	14 200	12 200	10 80
14·0	20 700	17 100	14 700	12 700	11 30

The cost of raw material at the time of writing is a £160, whilst a competent mechanic in a reasonably equipped workshop can easily complete the task inside t months.

Fringe spacing in interference microscopes

By F. R. Tolmon and Jill G. Wood, B.Sc., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 14 *March*, 1956]

In interferometers employing fringes of constant thickness, where the incidence is normal or very nearly so, the fringe spacing obtained is accepted as equivalent to half the wavelength of the monochromatic light employed. However, in the case of interference microscopes, with high-powered objective lenses producing strongly convergent incident light, experiments show that the equivalent value of the fringe spacing is approximately 10% greater than half the wavelength, a discrepancy undoubtedly due to the obliquity of the rays. The effect is of importance when using interference microscopes for accurately measuring the heights and depths of shallow features on surfaces.

The standard of length in all interferometers is the wavelength λ of the monochromatic light used and in simple interferometers, for measuring the flatness of surfaces, the fringe spacing is $\lambda/2$ for all practical purposes. Where a high accuracy is required in gauge measuring interferometers it is necessary to evaluate the fringe spacing more precisely by including an obliquity correction due to the slight angle of incidence of the light, as well as corrections for changes in the value of λ due to atmospheric conditions such as pressure, temperature, and humidity. These corrections are usually small and are neglected in interference microscopes where such high precision is not achieved. However, it was recently noted when measuring the depths of shallow features with an interference microscope at the National Physical Laboratory that the results obtained were significantly different from those found when the depths of the features were determined by means of the Kösters(1) and N.P.L.(2) types of gauge measuring interferometers. Since the fringes in interference microscopes are produced in strongly convergent light, whereas the fringes in gauge measuring interferometers are formed in collimated light, it seemed likely that the crepancy in the fringe spacing in the former instrument due to the obliquity of the rays emerging from the microsc objective.

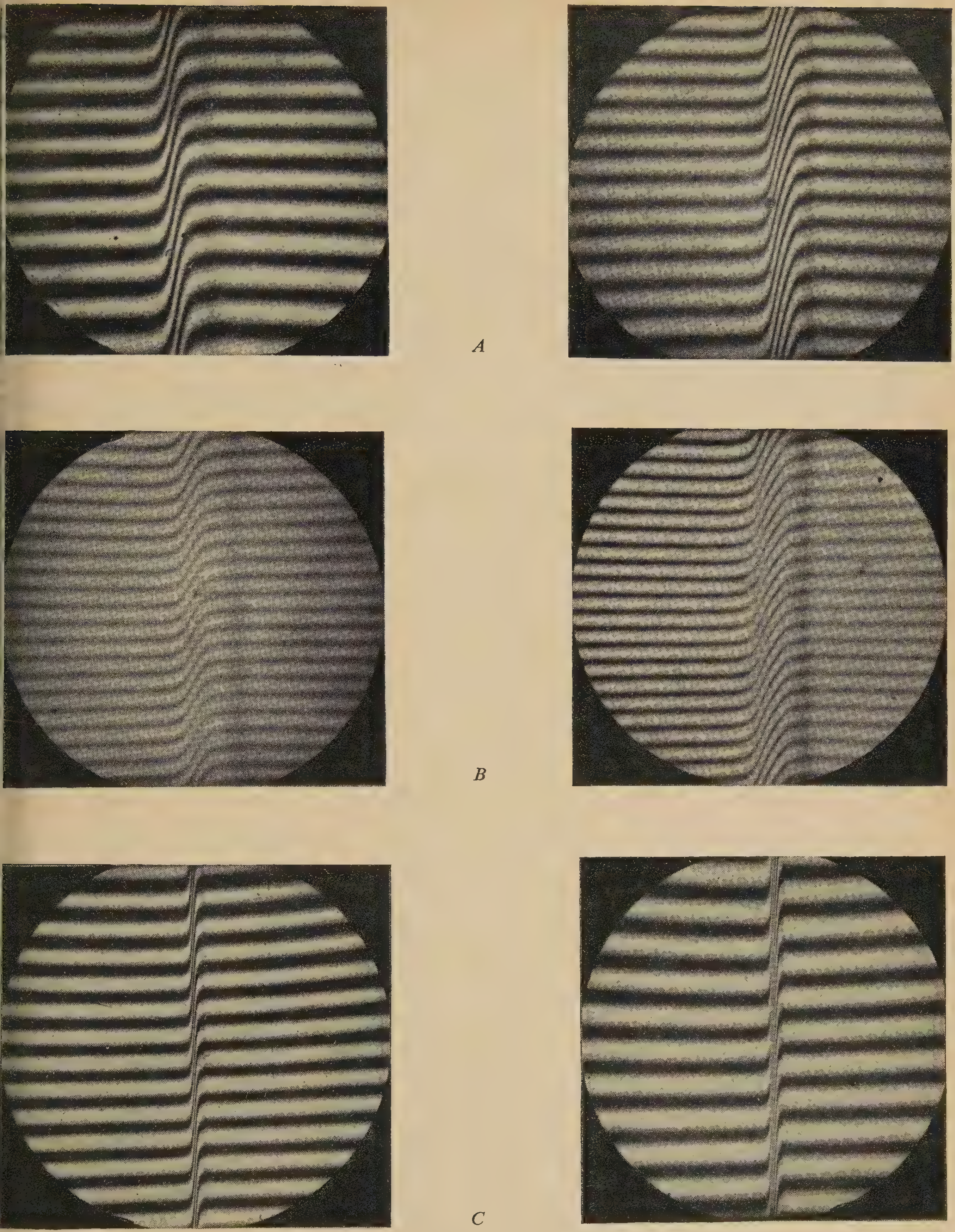
In interferometers which employ the system of fringe constant thickness produced in wedge-shaped air f between two nearly parallel reflecting or semi-reflec surfaces, the effect of the obliquity of the rays may easil derived from the general equation for the interference of li

$$p\lambda = 2t \cos \theta$$

In this equation p is the order of interference, λ is the w length in air, t is the thickness of the air film and θ the a of incidence of the rays with respect to the normal to on the reflecting surfaces. Thus for unit change in p the cha in thickness Δt is given by

$$\Delta t = \lambda/(2 \cos \theta)$$

and this corresponds to the fringe spacing or contour inte of the fringes. If θ is zero, normal incidence, the fri



Interferograms of steps on standards *left* S3 and *right* S4 taken on interference microscopes

A, Linnik-Zeiss (×310); *B*, Hilger and Watts high power (×385); *C*, Hilger and Watts low power (×85).

spacing corresponds to a change in the value of t equal to $\lambda/2$ but in the Fizeau type of length measuring interferometer the incident beam is deliberately inclined to the normal to the surface under test at a known small angle θ, in order to separate the incident and reflected beams. In consequence the fringe spacing is given by $\lambda/(2 \cos \theta)$ where θ is the small constant angle of incidence of the light.

A simple calculation of this nature cannot, however, be made for an interference microscope, but the necessity for a similar type of correction is apparent from a consideration of the optical system. If the two optically balanced paths of a Michelson type interference microscope are visualized superimposed upon each other, the usual wedge-shaped air film is obtained between two nearly parallel reflecting surfaces, and this arrangement is illuminated by rays emerging from the microscope objective at angles which vary from normal incidence at the centre of the lens to high obliquity at the edges. In combination these convergent rays of varying incidence behave as an oblique beam with a large effective angle of incidence and so cause a significant increase in the value of Δt. The actual performance of any one objective lens is difficult to assess and, furthermore, lenses of various numerical aperture are used in different instruments so that theoretical computation of the fringe spacing is not practicable. It was decided therefore to make special stepped standards for an experimental determination of the value of the fringe spacing in any interference microscope.

Each standard consisted of a rectangular glass proof plane $2 \times 1\frac{1}{2} \times \frac{3}{4}$ in. (50 × 38 × 19 mm) on to which aluminium was evaporated in two stages to form a shallow step. The surface of the proof plane was first completely covered with a thin layer of aluminium; a shield was then placed over one-half of the surface and a second layer of aluminium evaporated on to the uncovered portion. The height of the resulting step could be controlled by varying the time taken for the second evaporation. Both surfaces, which were made fully reflecting to eliminate changes in phase loss, were obtained flat to within 0·000001 in. (0·025 μ). The height of the step was measured in a Kösters interferometer using the green light of mercury-198, the measurements being made as close as possible to the actual step.

Six such standards, $S1$ to $S6$, were formed to cover a range up to 0·00009 in. (2·3 μ) and were used to calibrate a Linnik–Zeiss(3) and a Hilger and Watts(4) interference microscope. In the latter instrument both the high and low p systems were tested, but the standards $S5$ and $S6$, which the largest steps, were omitted as the depth of foc 0·00005 in. (1·3 μ) only. The results are tabulated i table and photographs of the steps of standards $S3$ an as seen in each instrument are shown in the figure. The were observed in mercury green light and measured in of the number of fringes displaced; the values given i table are the mean of two sets of observations. Compa with the measurements made in the Kösters interfero provided the correction factor for each instrument teste

Confirmation that the variation in the value of the f spacing may legitimately be attributed to the obliquity light emerging from the microscope objective was pro by stopping down the objective lens. The effective dia of the lens was reduced in stages until the definition an of the field had deteriorated to the limit for visual examin of the fringes at a diameter of 0·015 in. (0·38 mm), at point the most oblique rays were eliminated and the spacing closely approached a value of $\lambda/2$.

In conclusion it is clear that, in high-power interfe microscopes (n.a. = 0·6), the fringe spacing is approxim 10% greater than the normally accepted value of $\lambda/2$. equivalent of one fringe is 0·000012 in. (0·3 μ) in me green light ($\lambda = 0\cdot5461\ \mu$).

Calibration of fringe spacing in interference microscopes
(0·00004 in. = 1 μ)

	Accepted height of step, measured in Kösters interferometer		*Step measurement in fringes*			*Percentage correction*		
				Hilger and Watts			*Hilger and Watts*	
Standard	*in.*	*fringes*	*Linnik–Zeiss*	*High power*	*Low power*	*Linnik–Zeiss*	*High power*	*Low power*
$S1$	0·000021	$1\cdot9_5$	$1\cdot8_5$	$1\cdot7_5$	1·9	5	11	3
$S2$	0·000032	$2\cdot9_5$	2·6	2·6	2·9	13	13	2
$S3$	0·000034	$3\cdot1_5$	$2\cdot8_5$	2·8	3·0	11	13	5
$S4$	0·000049	$4\cdot5_5$	4·1	4·1	4·5	11	11	1
$S5$	0·000069	$6\cdot4_5$	$5\cdot9_5$	—	—	8	—	—
$S6$	0·000087	8·1	7·5	—	—	8	—	—
Mean percentage correction factor						9	12	3
Numerical aperture of objective lens						0·60	0·65	0·30
Equivalent fringe spacing in mercury green light (in.)						$0\cdot000011_7$	0·000012	0·000

ACKNOWLEDGEMENTS

The authors desire to acknowledge the assistance rend in the preparation of the standards, by members of the Division, National Physical Laboratory.

The work described above has been carried out as pa the research programme of the National Physical Labor and this paper is published by permission of the Direct the Laboratory.

REFERENCES

(1) Barrell, H. *Research*, **1,** p. 533 (1948).
(2) Barnes, D. C., and Puttock, M. *Engineer*, **196,** p (1953).
(3) Kinder, W. *Zeiss Nachrichten*, p. 91 (1937).
(4) Perry, J. W. *Research*, **8,** p. 255 (1955).

Laboratory and workshop notes

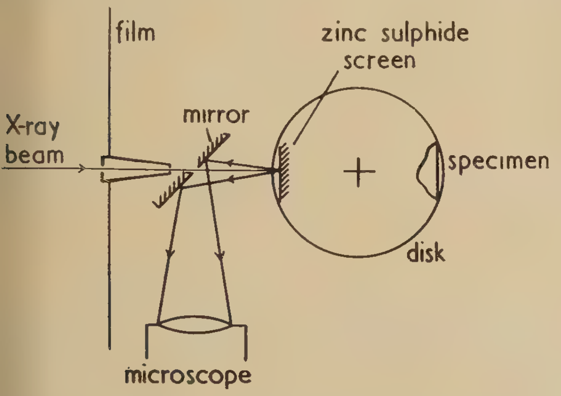
nple visual method of accurately positioning a specimen relative to an X-ray beam

P. J. Holmes, B.A., and P. D. Fochs, B.Sc., Ph.D., Inst.P., Research Laboratory, Associated Electrical Industries Ltd., Aldermaston, Berks.

[*Note received* 5 *September*, 1955]

1* has described a back-reflexion X-ray camera designed the examination of pre-determined points, on poly- alline metallographic specimens; an ionization chamber associated equipment are required and the specimen can ositioned within 0·02 mm. However, our own studies ructural defects in monocrystals did not require such sion, and therefore we developed a much simpler visual od of setting which enabled us to get the trace of a allographic feature consistently at the centre of a Laue within 0·1 mm.

e principle of the method is indicated in Fig. 1. The sulphide fluorescent screen is viewed in a low-power oscope with the aid of a suitable mirror at 45° to the



g. 1. Plan of experimental arrangement for positioning a specimen relative to an X-ray beam

y beam, and the cross wires set on the centre of the green escent spot. The specimen is then substituted for the n and positioned so that the required feature is in turn ed on the centre of the cross wires. The mirror can then emoved and a Laue back-reflexion photograph taken.

e only additions required for a standard Unicam gonio- r are a specimen holder (Fig. 2) and a plane mirror. specimen holder consists essentially of a brass disk on h the specimen and a zinc sulphide screen are mounted pposite ends of a diameter, so that a simple rotation of disk through 180° enables the two to be interchanged. disk is located by two diametrically opposite pegs which ge in a groove on the supporting bracket fixed to the ometer head; a compression spring on the bearing makes whole mounting quite rigid. It was found desirable to p the oscillation mechanism of the goniometer head making the preliminary adjustments.

e plane mirror was made of $\frac{1}{16}$ in. polished steel with a of $\frac{1}{16}$ in. diameter in its front surface, opened out to at the back to allow the primary beam of X-rays to through obliquely without the loss in intensity that d be associated with the use of a thin aluminized cover The mirror is mounted on a solid brass bracket which hooks over the top of the casette and can thus be removed or adjusted without disturbing the specimen or camera.

Being relatively close to the specimen, the hole in the mirror partially obscures a small region of the field of view, and in order that this should not be the region of interest, a slight rotation and displacement of the mirror is, in fact, made.

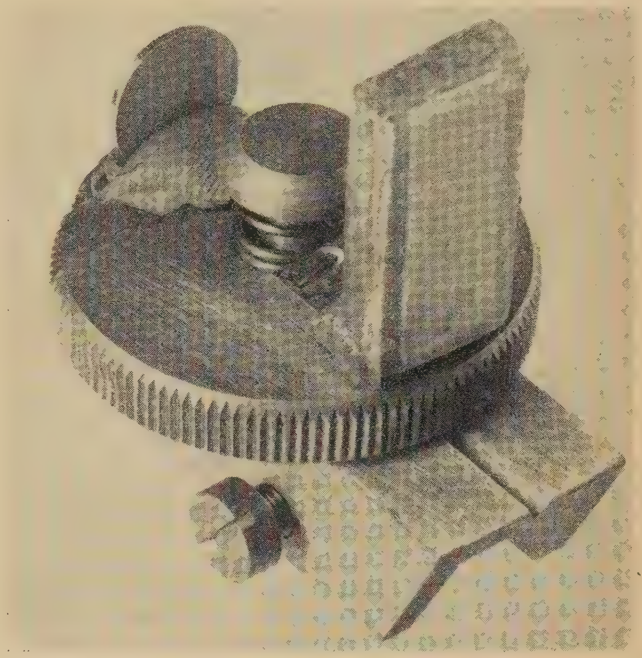


Fig. 2. Goniometer head attachment

The authors' thanks are due to Dr. T. E. Allibone and the Admiralty for permission to publish this note.

---

* Cahn, R. W. *J. Sci. Instrum.*, **30**, p. 201 (1953).

An illuminator for detecting air lines in glass tubing

By S. J. Morrison, B.Sc., A.M.I.E.E., and S. M. Phillipson, A.M.I.E.E., The British Thomson-Houston Co. Ltd., Rugby

[*Note received* 14 *September*, 1955]

The presence of bubbles of gas in a glass melt gives rise to defects in glassware made from the melt. In the case of bulbs and pressings, the defects are known as "blisters" or "seed." In the manufacture of glass tubing and rod the bubbles are elongated by the drawing process and become long threads of relatively small bore, which are known as "air lines." These air lines can give rise to difficulty in lamp and valve manufacture and in the construction of glass apparatus generally, by the expansion of trapped gas during sealing operations. Even when it is possible to carry out the sealing operations successfully without bursting any bubbles, trouble may arise subsequently during the normal operation of the device. For example, failure of glass seals which have to operate in a radio-frequency field has been known to occur if a gaseous discharge takes place in the trapped gas in an air line.

Unfortunately, it is difficult in glass manufacture to ensure that certain grades of glass (e.g. borosilicate glass) will be entirely free from air lines of any degree, and there are usually a number of fine air lines present even in the highest quality tubing. It is therefore essential for routine inspection purposes to have some means by which air lines of all degrees can be identified easily and rapidly, so that the size and frequency of occurrence of gross air lines can be assessed relative to some predetermined standard of quality.

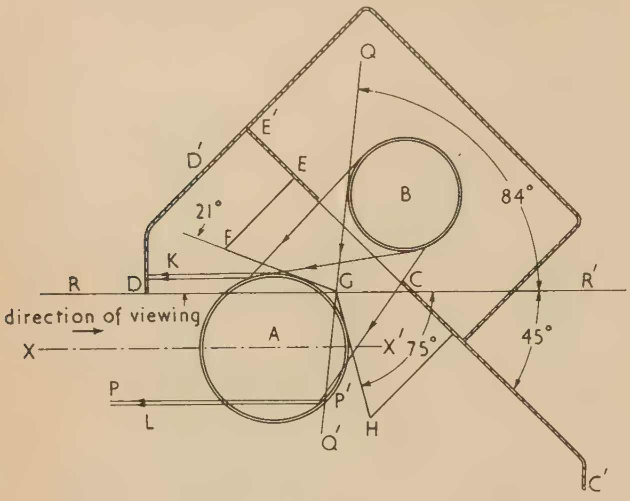


Fig. 1. Optical design of glass tube illuminator

K, unwanted reflexion; *L*, reflexion from inner surface.

Under normal lighting conditions in factories and laboratories (whether from natural or artificial light sources) it is usually difficult to see the air lines, particularly in small diameter glass tubing. The difficulty arises from high luminance reflexions of the light sources which distract the observer's attention from the air lines, especially if the reflexions come in or near the direct line of view. This problem has been overcome in the design of a special type of illuminator described below.

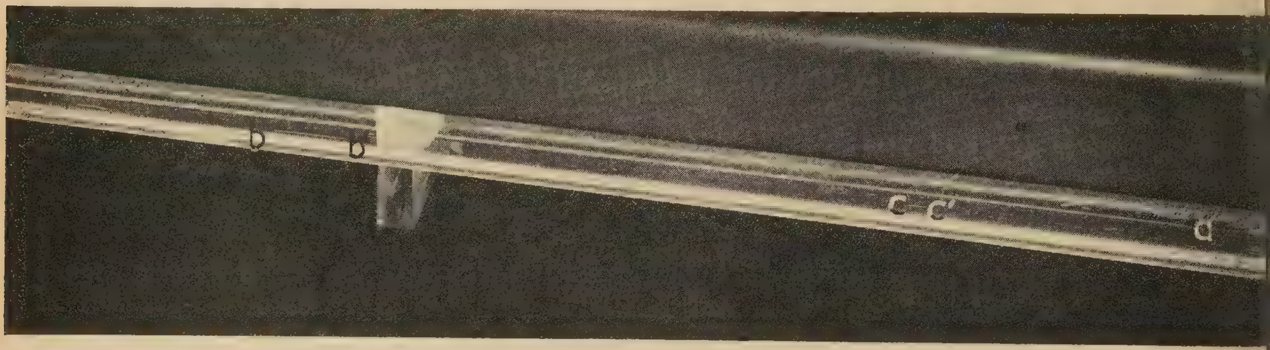


Fig. 2. Glass tube under illuminator

The optical design of the illuminator is illustrated in Fig. 1. The glass tubing *A* to be examined is held close to and parallel with a tubular fluorescent lamp *B*. The air lines can be seen as threads of high luminance against the dark background of the black screen *CC'*, which is inclined so that it is not illuminated by the lamp. In order that air lines at or near the centre line *XX'* can be clearly seen, the position of the lamp is so arranged with respect to the specimen and the direction of viewing that reflexions of the light source are confined to narrow bands at the top and bottom of the frontal aspect of the tube. The troublesome high luminance reflexion on the top of the specimen is screened from the observer by the screen *DD'*, which also serves to screen the lamp from c vision, and to screen the specimen from illuminatio extraneous light sources. The lower reflexion on the surface of the tube is of relatively low luminance, and not constitute a serious difficulty. Most of the residual reflexions from within the black painted lamp housin prevented by a third screen *EE'*.

In order to simplify the use of the illuminator for tubing of all sizes, V-blocks are provided at *FGH*. T are arranged in such a way that the circular cross-sectio the tubes will make the correct intersection with the *PP'*, *QQ'*, *RR'* irrespective of the diameter of the tube.

The efficacy of this method of inspection can be ju by the photograph of a specimen tube under the illumi (Fig. 2). A gross air line, starting at *a*, can be clearly and also numerous minor air lines such as those marke and *cc'*.

The lighting unit is of all-metal construction, an approximately 5 ft in length so that the entire length stick of glass can be observed. Shorter units can be structed if desired. It is shown mounted on a sta bench operation, and its angle of inclination may be adju to suit the eye-level of the observer, whether standin seated at the bench. The V-blocks to which the tube presented are made of clear Perspex, so that the illumina of the specimen is not interrupted.

The illuminator is relatively simple to construct and it been found to give a very clear visual indication of air in tubing. It has also been found to be satisfactory identifying other defects such as minute surface crack bulbs, and pressure checks in pressings. It can be use the examination of other transparent materials such as qu or plastics.

The authors wish to acknowledge the advice and assist of colleagues in the British Thomson-Houston Rese Laboratory in the preparation of this note.

Thin film abrasion tester

By J. C. KELLY, B.Sc., Grad.Inst.P.,* Division Metrology, National Standards Laboratory, Commo wealth Scientific and Industrial Research Organizatio Sydney, Australia

[*Note received* 1 *September*, 1955]

In the course of an investigation into the use of evapor metals as graticules(1) the need arose for a device to mea

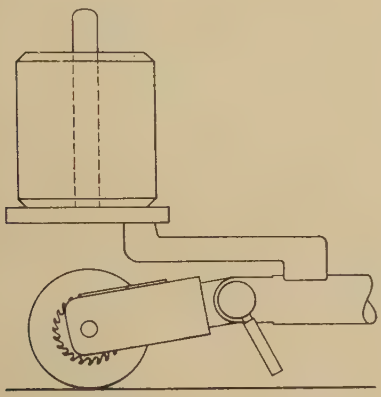
---

* Now at University of Reading, Berks.

adherence and durability of evaporated metals on glass
other substrates. Numerous devices designed to test
evaporated films have appeared in the literature(2–5)
there are others which could readily be adapted for the
ose.(6–7)

number of these testers use a single small fixed abrader.
accentuates trouble due to the pile-up of removed
rial on the abrading surface. To minimize this and other
ulties it was decided to use a rotating wheel as an abrader,
averaging out local irregularities and spreading the wear
a much larger surface. A further advantage of this type
brader is that curved surfaces can be tested with better
oducibility.

simple means of accomplishing this is to have the abrader
el mounted with a ratchet hub on a counterbalanced arm
provision for adding known masses above the centre of
abrader. Provision for adjustment is made to allow for
pieces of different thickness (see the figure). The arm is



brader head with adjustable wheel mounting and mass carrier

oted on ball races near its centre with an adjustable
nterweight at the free end. The test piece is reciprocated
ow the abrasion wheel by a motor through a variable
ed control. A counter records the number of complete
kes.

he abrasion wheel rolls to a new portion of the wheel on
forward stroke and abrades on the return stroke. The
het should have the largest prime number of teeth possible
maximum utilization of the wheel. A prime number
ures that only for combinations of wheel diameter and
ke length which rotate the wheel an integral number of
es will the wheel wear unevenly. This can easily be
ided.

he tester as constructed uses a wheel 1 in. in diameter
½ in. wide. The speed, at a stroke of 1½ in., is variable to
naximum of 4 c/s. The ratchet has twenty-nine teeth.
bbers of a hardness greater than 70 Shore A units are
able material for the abrasion wheel. For coatings
ch are very resistant, e.g. chromium or magnesium
ride, an abrasive loaded rubber is used. For routine
k a visual estimate of the damage caused by a fixed
nber of strokes is usually sufficient. An accurate com-
ison of the durability of layers may be had by measuring
amount of material removed. This may be suitably done
h an interference microscope.

his abrasion tester was devised as part of the research
gramme of the Division of Metrology, Commonwealth
entific and Industrial Research Organization.

REFERENCES

(1) Kelly, J. C., and Dawes, H. A. *Austral. J. Appl. Sci.*, **5**, p. 339 (1954).
(2) Heavens, O. S. *J. Phys. Radium*, **2**, p. 355 (1950).
(3) Packer, D. M. *J. Opt. Soc. Amer.*, **37**, p. 983 (1947).
(4) Townsley, M. G. *Rev. Sci. Instrum.*, **16**, p. 143 (1945).
(5) *Foto-Kino-Tech*, **4**, p. 76 (1950).
(6) Beams, J. W., Walker, W. E., and Morton, H. S. *Phys. Rev.*, **87**, p. 524 (1952).
(7) Burwell, J. T., and Strang, C. D. *J. Appl. Phys.*, **23**, p. 18 (1952).

A two-circle Geiger counter mounting

By R. Bones, Ph.D., A.Inst.P.,* Department of Chemical Crystallography, University College, London

[*Note received* 1 *July*, 1955]

The apparatus described here was designed for accurate measurements of the diffuse scattering from single crystals of urea, for which purpose it was necessary to be able to move the Geiger counter in three dimensions.

The principle of operation can best be explained by reference to Fig. 1. The Geiger counter is enclosed in a container *G* which is supported by an arm *H* and is inclined at an angle

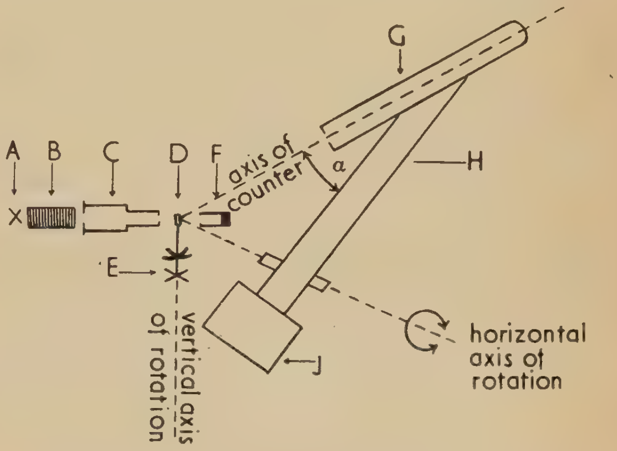


Fig. 1. Diagram to illustrate principle of operation

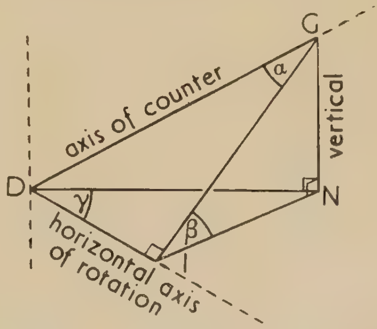


Fig. 2. Diagram to illustrate scale reading corrections

α (about 30°) to that arm. The arm is pivoted about a horizontal axis of rotation passing through the crystal *D* and is counterbalanced by a weight *J*. The whole of this part of the apparatus can rotate about a vertical axis, which is also the axis of rotation of the crystal and the arcs *E*. X-rays from the focus of an X-ray tube *A* fall upon the monochromating crystal *B* and are then collimated by *C*; the direct beam is stopped by a beam-trap *F*.

---

* Now at University of Hong Kong.

Rotation about the horizontal axis moves the Geiger counter over the surface of a cone which has a semi-apical angle of 60°. The vertical angle in which readings can be made is therefore limited to 60° (approximately the angle covered by a cylindrical camera). For angles greater this the crystal has to be reset about another axis.

In order to obtain the horizontal and vertical settin the counter simple corrections have to be applied t scale readings. In Fig. 2, *D* again represents the cr and *G* the Geiger counter, The two scales shown o instrument (Fig. 3, *L* and *S*) give, respectively, the ang

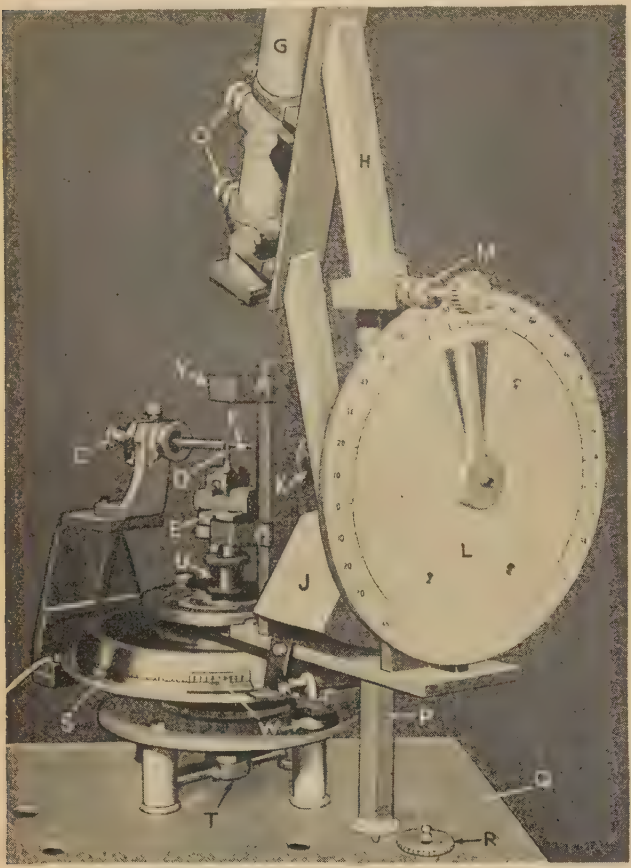


Fig. 3. Apparatus showing vertical circle (*L*) and slow-motion drive (*M*)

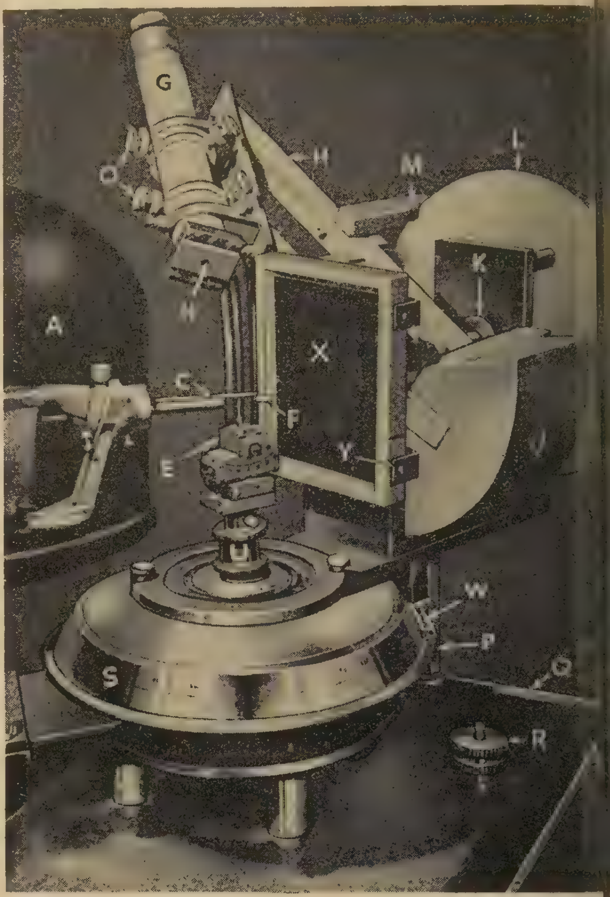


Fig. 4. Apparatus as seen from above

A, X-ray tube.

B, monochromator.

C, collimator.

D, crystal.

E, arcs.

F, backstop.

G, Geiger counter container.

H, arms carrying the Geiger counter container.

J, counterbalance weight. This is a bucket-shaped container filled with lead shot.

K, two bearings on which *H* pivots. These are two self-centring ball-races.

L, vertical scale.

M, slow motion drive for the counter. This consists of a rubber bung turned to shape on a lathe. A groove in the bung grips the side of the scale *L*, and can be rotated by means of the knob at the end of the spindle passing through it. This provides a very smooth and positive action and has been entirely successful in operation. It is perhaps the most important detail of the whole design.

N, aperture in front of the Geiger counter, consisting of a hole 2 mm in diameter punched in a thick sheet of lead accurately centred on the axis of the counter.

O, two sets of three adjusting screws by means of which the Geiger counter can be centred in its container.

P, supporting leg to take the weight of the apparatus off the centre bearing. At the lower end of this leg is a single ba bearing which can be raised and lowered by means of a knurl screw. This ball-bearing presses on to plate *Q*.

Q, sheet of $\frac{3}{8}$ in. thick plate glass which is accurately flat one thousandth of an inch.

R, four levelling screws bearing upwards into the glass pla *Q*. At the upper end of these screws are ball bearings whi rest in indentations in the glass plate above.

S, horizontal scale. The whole apparatus has been design around this scale and centre bearing which was adapted fro part of an old Bragg ionization spectrometer.

T, locking device for the arcs and for the vertical axis rotation of the Geiger counter.

U, height adjustment for the arcs, consisting of a thread collar which screws over the centre spindle and which can locked by means of a locking nut below it.

V, slow motion control and vernier controlling the rotati of the crystal (also part of the original Bragg spectrometer).

W, slow motion control and vernier controlling the rotati of the Geiger counter mechanism about the vertical axi (another part of the original spectrometer).

X, flat film holder. This was used for taking setting phot graphs of the crystal.

Y, springs holding the removable plate holder *X* in place.

Z, cable connecting the Geiger counter with the power supp and the rest of the electronic apparatus.

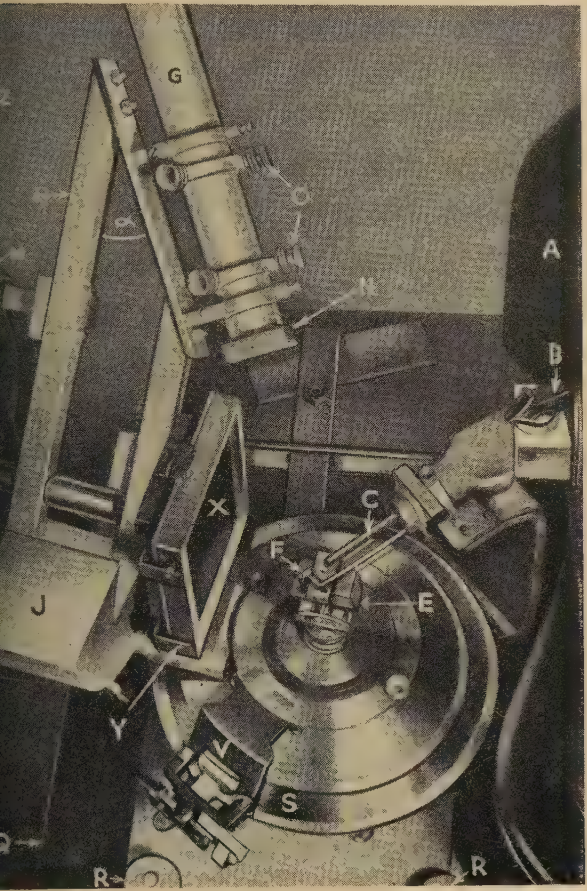
he angle γ that DI, the horizontal axis of rotation, , with some zero of reference. The true angle of ion of the counter is $\angle GDN$.

$$\sin \angle GDN = GN/GD$$

$$GN = GI \sin \beta \text{ and } GI/GD = \cos \alpha$$

e $$\sin \angle GDN = \cos \alpha \sin \beta \qquad (1)$$

ngle $IGD = \alpha$ was designed to be 30° but in practice d out to be 29°12′.



g. 5. Apparatus showing film holder (X) and front view of Geiger counter mounting

See beneath Figs. 3 and 4 for key.

t the zero correction of the horizontal reading on scale S aken when the counter is at its maximum elevation, i.e. $\beta = 90°$, $\gamma = 0°$. The angle $\gamma = \angle NDI$ may then egarded as the correction to be applied to the reading he horizontal scale, which is caused by the movement of projection of the counter on a horizontal scale nearer to xis of rotation as the counter is raised.

$$\tan \gamma = IN/ID$$

$$IN = IG \cos \beta \text{ and } IG/ID = \cot \alpha$$

ce $$\tan \gamma = \cot \alpha \cos \beta \qquad (2)$$

quations (1) and (2) give the vertical and horizontal es of the counter position.

gs. 3, 4 and 5 are photographs of the diffractometer.

he distance between the crystal and the aperture in front he Geiger counter was 11·4 cm. The collimator was 10 cm long and had a 1 mm aperture at each end. The distance between the end of the collimator and the crystal was 0·6 cm and between the end of the collimator and the backstop was 1·5 cm. The two scales were approximately 18 cm in diameter. The plate holder held a film $3\frac{1}{4} \times 4\frac{1}{4}$ in., i.e. quarter-plate.

My thanks are due to Mr. V. Narduzzo, of the Department of Chemical Crystallography, University College, London, who was largely responsible for the construction of the apparatus and for some of the details of the design.

A high vacuum magnetic mercury cut-off

By R. A. W. Haul, Dr. Ing., Dr. habil., and E. R. Swart, M.Sc., National Chemical Research Laboratory, Pretoria, South Africa

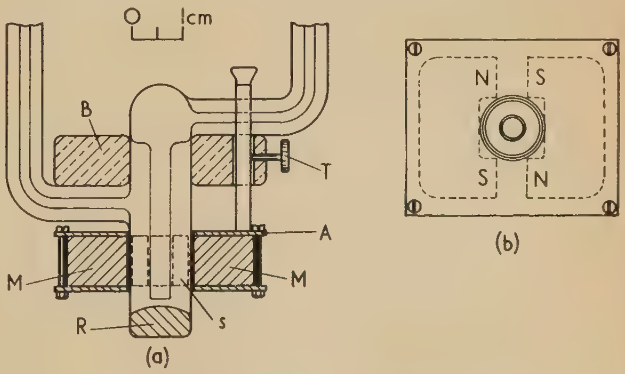
[*Note received* 17 *October*, 1955]

Various types of mercury cut-offs have been described in the literature from time to time, including some which are magmetically operated. As long as the pressure difference involved is small, no difficulty arises with the conventional Y-type cut-off. The ability to handle large pressure differences, however, is not easily achieved, especially with a cut-off of small volume, and generally results in the risk of flooding the system with mercury.

In some of our work on gas adsorption, which necessitated the rigorous exclusion of contaminating substances, mercury cut-offs were required in the capillary section of the apparatus to take the place of greased stop-cocks. The two main conditions were:

(i) that the cut-off should have a volume as small as possible, in order to avoid undue increase in dead space volume;
(ii) that it should be able to deal with pressure differences up to at least one atmosphere in both directions. In addition it was essential that the cut-off should:
(iii) be able to maintain a vacuum of 10^{-6} mm or less;
(iv) be able to be closed readily at all pressures;
(v) cause no appreciable change in the volume of the system during its operation;
(vi) be able to cope with sudden changes in pressure, due to an accident or unskilled handling, without flooding the system with mercury.

As far as could be ascertained none of the cut-offs described in the literature were suitable, although the type described by



Section through the cut-off

R, mercury reservoir; M, two permanent magnets; S, stainless steel ring; B, Bakelite support; T, thumb screw; A, aluminium holder.

Hibben* fulfils all the above conditions except No. (iv). The cut-off shown in the figure was therefore developed.

In order to close the cut-off the stainless steel ring *S* is first pulled down into the mercury reservoir *R* by means of the magnets *M*, which are allowed to drop to the bottom of their travel. The mercury is then frozen in position by immersing the cut-off in a small Dewar flask containing an alcohol-dry ice freezing mixture. In order to open the cut-off the flask is removed and the magnets raised and clamped in position by means of the thumb screw *T*. The opening of the cut-off may be speeded up by immersing it in a beaker of warm alcohol. At small pressure differences the cut-off can be operated without the necessity of freezing the mercury. Mercury vapour is prevented from reaching the adsorbent by means of a cold trap, consisting of a capillary U-tube slightly widened at the bottom.

The two small Alnico horseshoe magnets (by J. Neill and Co., Sheffield), are held in position by aluminium plates *A* as shown in the figure. Permanent magnets were found to be convenient, although a solenoid could be used instead.

Cut-offs of the above type have been in continuous use in this laboratory for some time and have been found to be completely effective in every way.

This note is published by permission of the South African Council for Scientific and Industrial Research.

* HIBBEN, J. H. *J. Amer. Chem. Soc.*, **50**, p. 1117 (1928); see also, SCHMIDT, O. H. *Rev. Sci. Instrum.*, **8**, p. 68 (1937).

A control valve for corrosive liquids

By J. HODKINSON, Ferranti Ltd., Moston, Manchester

[*Note received* 19 *September*, 1955]

It is often necessary, in factory or laboratory operations, to have a glass container with an attachment for regulating the flow of a corrosive acid, to be used for etching or tapering purposes. The procedure is to use an aspirator with tubular and glass stopcock and the liquid flow can then be regulated by opening the stopcock to the desired position.

In practice, however, this arrangement has several disadvantages.

(i) If the same acid is required to be used more than once, particles of material from the previous etching process, and stray particles of impurities may contaminate the acid. These particles have a tendency to get into the ground section of the key of the tap, and wear the barrel, which in turn causes leakage, or binding of the key in the barrel.

(ii) If the acid is left in the bottle with the stopcock not in use for several days, the acid creeps along the ground section of the key and congeals around the top and bottom of the stopcock. When the apparatus is required to be used again, the stopcock may be very difficult to manipulate and breakages are liable to occur for this reason. When using a stopcock of this design it is advisable to hold the barrel with one hand and turn the key with the other. The hands of the operator are placed in a dangerous position whilst operating the tap, because they are exposed to the acid and also to pieces of broken glass if breakage should occur. The following design (as shown in the figure) has been developed and has been found to have many advantages over the previous method.

A piece of tubing, 17 mm external diameter and 25 cm long, is fused to the tubulure of the aspirator, so that it rests parallel to the aspirator, and at a distance of about 5 cm from its outer surface. This is best achieved by joining at one end of the 25 cm tube a short length of tubing, similar in size to the tubulure on the aspirator. This short length of tubing is attached to the 25 cm long tube at an angle of 90°. A length of capillary tube, 7 mm external diameter and bore, can also be fused to the 17 mm external diameter at the same end as the side tube to form the outlet n the tubulure on the aspirator and the side tube on the 2 tube can then be cut to the required length and sealed tog to form one complete unit.

The usual shape for the outlet is a swan neck, but shapes can be formed to suit the requirements of any parti job. A 30 cm length of glass rod *R*, 8 mm in diameter, with a glass ball *B* of suitable size at one end, is placed the centre of this tube, so that the ball rests in the seat just below the level of the tubulure. The glass ball is gr into the seating by rotating the glass rod in such a ma that the axis of the rod remains coincident with the ax the tube. Fine mesh carborundum powder in water is as the grinding paste, and a very good liquid-tight join be made between the ball valve and its seating. The end of this tube is fitted with the valve centralizer *D* adjustment screw *Q*. These components are made of thene, a material which is resistant to corrosive acids.

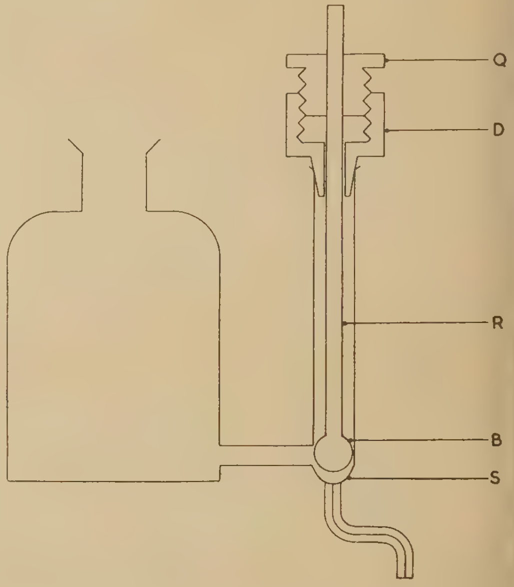


Diagram of control valve for corrosive liquids

The centralizing component *D* fits tightly into the t the 17 mm diameter glass tube. A hole of 12 mm dian is drilled through this component and the upper porti provided with a suitable thread. The flow regulator h hole drilled through the centre so that the glass rod tightly and prevents slipping, and is provided with a sui thread to screw into component *D* to give a fine adjust

This new design has the following advantages.

(i) The ball valve is always immersed in the acid therefore stiff or sticking valve trouble does not occur.

(ii) Minute particles of material or dust, settling ar the ball valve when closed, cannot cohere because the immersed in the acid. Immediately the valve is opene particles are washed out through the nozzle. For the re stated above it is also very unlikely for the valve to seiz

(iii) It can be very easily operated by one hand, whi a great advantage in many cases when working in a con space; also the control is situated above the level of the in the bottle, and therefore the hands of the operator ar removed from the danger zone in case of breakage.

Correspondence

Conduction-cooled vapour traps

te published in this *Journal*(1) has led us to make some urements of the temperature of the baffle of a 5 in. eter cold trap similar in design to that of Pollard.(2) ad been using the trap for some time with satisfactory ts.

lf an hour after filling the 1 litre capacity Dewar flask liquid air, the centre of an edge of the upper baffle plate reached −100° C, and after an hour it had reached)° C. The temperature remained within a few degrees minimum for 4 h and after 5 h it had risen to −130° C, g to the lowering of the level of the liquid air in the iner. The pressure in the system was no greater than mm of mercury.

arch Laboratories, V. A. Heathcote
General Electric Co. Ltd.,
bley, Middlesex.

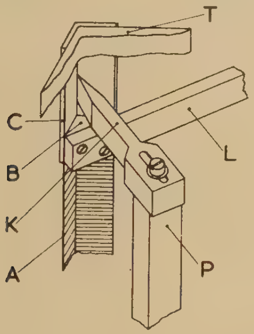
REFERENCES

ARTIN, A. J. *J. Sci. Instrum.*, **32**, p. 400 (1955).
OLLARD, J. E. *Rev. Sci. Instrum.*, **24**, p. 996 (1953).

Angle-spring hinges

le and compensated angle-spring hinges were described paper published on p. 336 of the September 1955 issue is *Journal*. The axis of a simple hinge tended to wander rotation, and this defect was reduced in compensated s by mounting two angle-springs back to back.

alternative way of reducing the defect is shown in the . The rotating end of the angle-spring *A* is clamped en the block *B* (to which the turning lever *L* is attached) n angle-clamp *C*; *C* is extended upwards, and carries ble or component *T* to be rotated. About 1 cm of *C* clear between *B* and *T*, and into the re-entrant angle is inserted a knife-edge *K*, carried on a pillar *P*. Knife-*K* presses gently into the re-entrant angle of *C* when the -spring is unstrained.



In the simple angle-spring, the original axis tends to track and tilt inwards along the diagonal from the corner angle of the spring. The angle of tilt is $(b/a\sqrt{2})\theta^2$, where θ is the angle of rotation and a the length and b the width of the spring. In the present arrangement, the inward movement of the corner of the spring is resisted by the knife-edge, which thus provides a definite axis of rotation. The angle-spring can then be made weaker than would otherwise be possible; in particular, its ratio of length/breadth can be made greater, permitting greater flexibility.

In a trial spring with $a = 10$ cm, $b = 1$ cm, rotations up to $\pm\frac{1}{2}$ rad were possible. When used unsupported, such a spring would have had an axis nutation of 15 min for a rotation of $\frac{1}{4}$ rad. With the knife-edge in position, the nutation was less than 1 min, and the drift less than 5 μ at the level of the block *B*, for $\frac{1}{4}$ rad rotation. The knife-edge was thus effective in stabilizing the axis against both drift and wobble; at the same time it introduced very little friction, since it had only to provide a minor correction.

The accuracy of performance depends on the matching of the knife-edge and the re-entrant angle into which it fits (the performance given above was obtained by a few minutes' work on the two surfaces). Alternatively a pin can be used instead of a knife-edge. The supporting pillar adds little to either the volume or the complication of the hinge. For many purposes, the stability of the simple angle-spring hinge is sufficient, but where something better is desired, the supported hinge is probably easier to construct than any other device giving a comparable performance.

Department of Natural Philosophy, R. V. Jones
University of Aberdeen.

An adaptable mechanism for converting rotary motion into a succession of linear movements

In the note by Mr. A. L. Sims, published on p. 35 of the January 1956 issue of this *Journal*, an adaptable mechanism for converting rotary motion into a succession of linear movements is described. An analysis of this interesting mechanism shows that it contains basically three rotating pairs (centre of arm 4; between 4 and 5; between 3 and 1) and one sliding pair between 1 and 2. It may therefore be easily reduced, or even deduced, from a rotating block linkage,(1) by the expansion of elements. Almost identical examples are found in rotary steam engines suggested by Cochrane and Reuleaux.(2)

41 Tudor Close, P. Grodzinski
Belsize Avenue,
London, N.W.3.

REFERENCES

(1) Grodzinski, P. *A Practical Theory of Mechanisms*, p. 58 (Manchester: Emmott and Co., 1947).
(2) Reuleaux, F. *The Kinematics of Machinery*, p. 369, plate 30 (London: Macmillan and Co., 1876).

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or imp
products. The Institute of Physics assumes no responsibility for the statements given below: information for these has
taken from literature supplied.

Electro-deposited copper foil. The Royal Mint Refinery, N. M. Rothschild and Sons, 19 Royal Mint Street, London, E.1.

The Royal Mint Refinery can supply electro-deposited copper foil in various thicknesses and widths. The range of widths quoted below enables the foil to be used for the production of copper clad laminate which is required for the manufacture of etched-foil, printed circuits.

The foil, which is bright and polished on one side and which has a matt surface on the other, has been successfully bonded to both rigid and flexible plastic laminates. The physical properties of the foil are in most respects similar to that of hard-rolled copper sheet; it is supplied in continuous length coils. The bulk of the foil at present being supplied is for the printed circuit industry, and the following is a general specification for this type of foil:

Purity: minimum 99·9%.
Conductivity: minimum 95% (I.A.C.S.).
Width: up to 42½ in. 51 in. foil will become available from July 1956.
Thickness: Generally any thickness between 0·001 in.–0·004 in. measured by weight.

Example

Nominal thickness (in.)	0·001	0·001 35	0·0027	0·004
Weight (oz/ft^2)	0·735	1	2	2·94

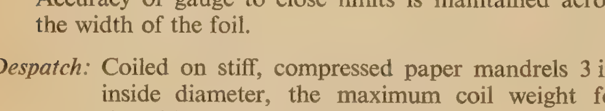
Accuracy of gauge to close limits is maintained across the width of the foil.

Despatch: Coiled on stiff, compressed paper mandrels 3 in. inside diameter, the maximum coil weight for the widest material being 100 lb.

Electro-deposited copper foil is, however, made in narrower widths and in thinner gauges than those specified above, the minimum thickness being 0·000 12 in.

Scintillation counter housing. A. Reid Manufacturing Co. Ltd., Peel Road, Wealdstone, Harrow, Middlesex.

The ARM 19 photomultiplier holder, illustrated in the figure, was designed in collaboration with the United Kingdom Atomic Energy Authority. When fitted with a photomultiplier and crystal, it forms a scintillation counter for nuclear radiations. The holder comprises a polished Dural tubular housing into which a photomultiplier tube can be inserted. At one end of the housing is a socket to receive the contact pins of the photomultiplier itself. The whole
assembly, together with the photomultiplier, is pressed
helical spring so that the photocathode end of the tu
located against the crystal at the opposite end of the hou
External connexion is made through a coaxial socket.
crystal is held by a retaining cap screwed to the opposite
of the housing. The cap is supplied with varying aper
to suit normal standard crystal sizes from 1 to 2 in.
holder will accept E.M.I. photomultiplier tubes types
6097, 6256, 9502, 9514, 6255 or 6094.



Scintillation counter housing

Field ratemeter. Ericsson Telephones Ltd. (Instru
Division), Beeston, Nottingham.

A battery-operated instrument, type 1368, has been devel
in conjunction with the Atomic Energy Research Estab
ment for geological surveying and the examination of
workings. When used with a β-probe unit, assay work
be carried out in the field. The ratemeter employs a junc
type transistor and four Geiger tubes. The count ra
indicated on a 50 μA meter calibrated in milliröntgens
hour. Five ranges are provided covering count rate
0–25 mr/h. The accuracy is related to the speed of resp
and by means of a switch can be set at either 10% or
Audible indication of the count rate is available if requ
All power supplies are derived from three 1½ V dry cells,
a corona stabilizer ensures that the instrument is unaffe
by changes of battery voltage over the range 4½–3 V.
ratemeter itself is ruggedly constructed and weighs 8
The complete equipment, including ratemeter, probe
with extension handle, canvas haversack, headphones, sa
holders and filling funnels for assay work, tools and spar
contained in a lightweight alloy case weighing 28 lb. in a

Decade capacitor. Servomex Controls Ltd., Crowbor
Hill, Jarvis Brook, Sussex.

A relatively inexpensive three-decade capacitor is avail
which is suitable when a moderate accuracy is required.
capacitor, which is rated at 350 V, covers the range 0·
0·999 μF with a guaranteed accuracy of 2%. The
lowest decades are constructed of silver mica capacitors
an accuracy of 1%; the highest decade uses paper capac
of 20% tolerance individually adjusted to within
Screening is provided by the steel case, which is fitted wit
earth terminal.

Transistor test apparatus. Baird Associates Inc., 33
versity Road, Cambridge, Massachusetts, U.S.A.

A test set has been designed for measuring the resistiviti
germanium or silicon samples over the range 0·1–100 Ω
This uses a probe method in which four probes are place
contact with the face of the sample. A known curre
passed between the outer electrodes and the potential betw
the inner electrodes is measured potentiometrically.
probe assembly contains four tungsten points mounted
carriage which is motor-driven along ground steel w
Spring loading of the electrodes, reproducible loading
uniform approach rate are claimed to make possible
reproducible results.

r examining completed transistors of any type, a test odel GP, has been designed for operation at frequencies 100 c/s to 1 Mc/s. The instrument can be set to ure hybrid coefficients, T-network coefficients, collector ation current, collector capacitance, α and β cut-off, ge feedback ratio, open-circuit resistances and channel voltage. Bias conditions are stated to be variable over le range.

ric “Bunsen.” Shandon Scientific Co. Ltd., 6 Cromwell Place, London, S.W.7.

lement of the Bunray electric heater can reach a temperaof 1470° F after one minute. The temperature, which is ted by either an energy regulator, sliding rheostat or transformer is much more accurately controlled than is ble with the conventional gas burner. The Bunray 300 has a 340 W heating element and has been designed ovide gentle heating with fine temperature control. The ay type 800 has an 850 W heating element and is claimed e suitable for boiling large quantities of liquids, conous distillation and other operations requiring a relatively heat source.

Electric “Bunsen”

e accessories include an energy regulator, suitable for only, which is rated at 1 kW; a water bath; hot plate and ible attachments; a clamp rod for supporting the heater ositions other than the vertical; and a quartz sleeve for heating element for use where the heater is used in a cal position and there is a danger of the heated substance g split.

tronic tachometer. E.M.I. Electronics Ltd., Hayes, Middlesex.

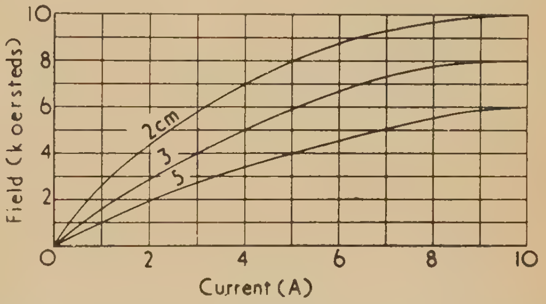
type 1 electronic tachometer is designed primarily for t speed measurement, but may be used where the tition rate of cyclic events is required. It accepts an nating or pulse voltage input, counts the number of cycles h occur during a preset period (controlled by pulses from c/s quartz crystal frequency standard) and displays the t on four dekatron tubes. The unit may be arranged, witch selection, so that the count is held for a short d, and then recounted, thus giving continuous monitor- Alternatively, by depressing a button a count can be made and held until the button is again depressed. In order to use the instrument to measure shaft speed, it is necessary to convert the rotary motion to a series of electric pulses proportional to the speed. Photoelectric transducers are available for this purpose. The accuracy claimed for the instrument is within 1 part in 10^4 or 1 pulse, whichever is the greater.

Miniature potentiometers. Carter Manufacturing Corporation, 21 Washington St., Hudson, Massachusetts, U.S.A.

The type 101-A range of potentiometers is characterized by the exceptionally small size of $\frac{1}{4}$ in. diameter × 0·430 in. long. The potentiometers are wire-wound with a minimum of 100 turns and have a precious-metal, sliding contact. The power dissipation is $\frac{1}{4}$ W at 20° C, and the resistances usually available are 680 Ω, 1, 1·5, 2·2, 3·3, 4·7 and 6·8 kΩ. It is claimed that the equivalent noise resistance is less than 100Ω.

Electromagnet. Newport Instruments (Scientific and Mobile) Ltd., Newport Pagnell, Buckinghamshire.

An electromagnet which is capable of producing magnetic field strengths up to 10 k oersteds at a 2 cm separation of the pole pieces with a current of 10 A is manufactured by this firm. The standard pole pieces are machined from mild steel, but if required they can be made from nickel iron and other special materials. The standard magnet is supplied with plain tips of 10 cm diameter. The pole piece tips are interchangeable, and angle or conical tips are available. Each coil is wound with approximately 95 lb of 0·064 in. diameter double glass-covered wire and has an average of 3550 turns. Resistance of one winding is 17·5 Ω. The maximum continuous current of coils in parallel is 8 A (600 W). Cooling is carried out by natural convection, but the manufacturers state that currents in excess of 8 A may be permitted for short periods.



Approximate performance data with 10 cm mild steel pole pieces

Cathode-ray tube with electrostatic focus. Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

A cathode-ray tube, type AW 13–36, which has been designed for compact television monitors and camera viewfinders and is intended for magnetic deflexion, has a low-voltage electrostatic focus lens. The lens requires a focus voltage of ±200 V about tube cathode potential, at a current of a few microamperes. The circular tube has a 5 in. diameter flat face with a metal-backed screen giving white fluorescence. The heater rating is 6·3 V, 300 mA, and the final anode voltage is 10 to 14 kV.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: E. Billig, W. Cochran, L. Cohen, P. G. Deo, J. E. Gould, D. K. McCleery, A. Nightingale, E. Nightingale, K. K. Schiller, M. W. Townsend, C. G. Webb.

Associates: R. E. Adlington, T. Ashton, R. Axe, K. H. Barker, C. J. Bennett, H. D. Blakelock, I. Brodie, E. W. Carpenter, D. G. Cole, W. E. Copsey, A. M. Davies, T. A. Duerden, M. J. Dumbleton, J. B. Earnshaw, G. F. Filbey, R. Forester, T. L. Goodfellow, D. J. Hine, D. R. Holmes, W. R. Inch, A. C. Jason, A. P. H. Jennings, H. Minshall, D. P. Morris, K. E. Parks, W. A. J. Preece, G. B. Redmond, J. G. Rider, R. C. Ritchie, D. A. Robins, S. C. Roy, A. Sanson, C. H. Sturley, D. Tittensor, W. Traub, A. J. F. Trott, H. V. Wainwright, O. M. White, G. R. Wignall, H. R. Wilson, J. O. Wood, M. M. Woolfson.

Eighteen Graduates, five Students and five Subscribers were also elected.

Conference on the physics of nuclear reactors

The Institute of Physics is arranging a conference in London on "The physics of nuclear reactors" from 3 to 6 July, 1956, which its President (Sir John Cockcroft) will open with an address on the scientific problems in the generation of nuclear power. The primary purpose of the conference is to inform members of the Institute, particularly those engaged in industry, of recent developments in reactor physics and cognate subjects, and to make known to them the problems awaiting solution. As it is likely that an increasing number of physicists will find themselves concerned with these subjects the Board of the Institute desires to assist its members to keep abreast of developments. A limited number of non-members will be able to attend the conference; application forms and further details may be obtained from the Secretary, The Institute of Physics, 47 Belgrave Square, London, S.W.1.

Retirement of Mr. A. J. Philpot

Whenever scientific instruments were being made or developed in this country in the last thirty years, one sooner or later expected to find the indefatigable Mr. A. J. Philpot somewhere around. It is therefore difficult for those of us still in harness to realize that he is about to retire from the Directorship of The British Scientific Instrument Research Association on whose staff he has been for thirty-six years. He was also for some time Director of the industry's trade association—The Scientific Instrument Manufacturers' Association of Great Britain Ltd. No doubt this unique situation enabled him, with his keen sense of humour, to write himself appropriate letters (and for all we know to telephone himself) about the need for more support for research from the industry.

This *Journal* has had the advantage of much good from Mr. Philpot and we hope that in his retirement h find time to give us even more. This is neither the tin place to recite all he has done for those who need instru and those who make them; we shall content ourselv remarking that as a Vice-President of The Institute of Ph of the Physical Society and of the Society of Instru Technology he has rendered valuable service. As Trea of the Physical Society he has been largely responsib the policy which has enabled the Society's famous a exhibition of scientific instruments to prosper in its surroundings, without loss to the Society.

We wish him much happiness and quietude in his ment and hope that he will occasionally come among help to solve some of the problems of the peculiar ind with which he has been associated for so long.

Terms used in a.c. power system studies

A thirty-page British Standard has been published the title *Guide to terms used in a.c. power system* (B.S. 2658: 1956). It has been based on proposals subm by the British Electrical and Allied Industries Res Association. Since it is intended as a guide rather merely as a glossary the definitions and explanation been made more detailed and descriptive than is usua British Standard glossary. Where a term is defined in a previously published glossary and in this guide the definition is recommended.

The contents cover the following: load response stability terms, synchronous machines, symmetrical ponents, governor characteristics, transformers, lines cables. Letter symbols for many quantities appear text and are collected for reference after the list of cont

It is intended to review the guide after a year. A re edition will then be issued which will include any cha found desirable. Copies may be obtained, price 6*s*., the British Standards Institution, 2 Park Street, London.

British Journal of Applied Physics

Contents of the June issue

SPECIAL ARTICLES

Science and technology in industry. By Sir John Cockcroft.
Stress waves in solids. By R. M. Davies.

ORIGINAL CONTRIBUTIONS

The mechanism of pulse temperature rise on the surface of thermionic cat
By R. Dehn.
Direct carbon replicas from metal surfaces. By E. Smith and J. Nutting.
An extension of the circle and sphere theorems. By G. Power.
Electron optics of X-ray tubes and the design of unbiased sharply-fo
cathodes. By A. R. Lang and D. A. G. Broad.
Apparatus for the measurement of time of impact. By P. L. Kirby.

NOTES AND NEWS

Correspondence

The suitability of Araldite D resin in photoelastic investigations. By
Amba Rao.
A note on the polarization due to oblique reflexion at an aluminized or si
mirror. By J. N. Hodgson.

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principle construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Squa London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicati from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Londo E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addre or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable advance. Single parts, so far as available, may be purchased at 10*s*. each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

SPECIAL ARTICLE

The language of instrument calibration and performance

y K. M. Greenland, B.Sc., Ph.D., F.R.M.S., F.Inst.P., The British Scientific Instrument Research Association,
Chislehurst, Kent

A critical discussion is presented of the terms used in describing the establishment of instrument scales and the performance of measuring instruments. Examination of a number of vocabularies and of unrecorded usage shows that many of the important terms have more than one meaning. Arguments are put forward in support of certain unique definitions consistent, wherever possible, with the original sense of the words. The discussion takes as a basis the new definitive glossary compiled by the British Standards Institution (B.S. 2643: 1955).

INTRODUCTION

use a technical language does not grow from a single ce, the meanings of its words inevitably become confused at when the need for a glossary of terms is felt a certain nt of restoration and reconstruction is necessary (unless intention is merely to make an unselective record of ing usage and mis-usage). This is sure to be unpopular some of the builders of the language and many of its . A revised vocabulary may, however, stand a good ce of being generally accepted if it keeps existing words ll employment, deferring to common usage whenever it lo so without confusion. On the other hand, every effort be made to limit the appropriation of general scientific ls for special meanings, otherwise the technical language mes a jargon.

the technical language associated with instruments two r sources are clearly distinguishable in the alternative nings which certain commonly used words have acquired. e two sources are the instrument makers and the early ument users. Some words, such as *calibration* and *lardization*, may mean one thing in an instrument work- and something quite different in a laboratory. Either nese examples is a word which already has its place in nary language but which has been given two special nings of which only one is in true harmony with its non meaning. Perhaps the reason for this can be found e history of the growth of the modern instrument industry. difficult to realize in these days of highly instrumented stries that until quite recently the demand for new uments came largely from scientific institutions, and cularly from the universities; moreover some of the ng instrument-making firms employed, in their early , craftsmen who had learned their trade and the terms opriate to the use of scientific apparatus in the workshops niversity laboratories. Is it not possible that in describing processes of manufacture the newly-established maker etimes bent to his purpose the scientific words with which ad become familiar in his commerce with his academic ons or during his apprenticeship in the university?

VOCABULARIES AND GLOSSARIES

ie present state of instrument terminology is marked by features, the difficulty of establishing a glossary with a ciently wide acceptance, and the consequent tendency for ons of the instrument industry and of instrument users onstruct what might be called *ad hoc* glossaries for their purposes. This latter practice has naturally aggravated ack of conformity of definitions.

An example of an attempt to establish an authoritative and universal vocabulary is found in the work of the International Electrotechnical Commission, an organization affiliated to the International Organization for Standardization (I.S.O.). In 1910 the commission appointed a Nomenclature Committee "for drafting an international list of terms and definitions relating mainly to electrical machinery." In 1938 the first edition of the *International Electrotechnical Vocabulary* was published.(1) Group 20 of this vocabulary deals with "Scientific and Industrial Measuring Instruments" and contains, in section 20–40, twenty-five terms relating to the characteristics of instruments. Its main value, as far as the present subject is concerned, lies in its usefulness as a translation dictionary, since each term is given in English, French and German. It does not include any of the "difficult" terms such as, for instance, *stability*. However, second editions of some of the groups of this vocabulary are now coming out and group 20 is under revision by a French committee; perhaps many more of the words now appearing in other, lesser, glossaries will be granted a place and a wise definition. (This is an appropriate opportunity to remark that although the title of a vocabulary may be qualified by some restricting term such as "electrotechnical" it is sure to contain many words which are of a general nature. Sectional glossaries therefore contribute to the terminology of instruments in general; the corollary is that it is a bad principle to give the contents a meaning only intended to apply within a restricted field.)

The American Standards Association has sponsored a very large glossary of electrical terms(2) covering much the same field as the International Electrotechnical Vocabulary. It has a section on instruments, meters and meter testing, defining a few terms of design and performance, though again no lead is given on the description of differing classes of error.

Among the very few general glossaries there is an official French *Terminologie du Service des Instruments de Mesure*(3) which was compiled for the benefit of government inspectors. While it is not the intention to deal in this article with foreign terminology, this French glossary is worthy of mention, not only because it demonstrates a striking similarity between French and English terminology (both in the words themselves and in the difficulties associated with their use), but more particularly because an interesting point is made in its preamble, on the scope of instrument vocabularies. A sharp distinction is made between terms intended to describe the characteristics of instruments used by physicists and metrologists with laboratory techniques and those applicable to instruments in industrial use. The *Terminologie* is of course intended for the latter category and so, in fact, are practically all other glossaries, especially those of the *ad hoc* variety. As a consequence, considerations of limits of error and the effect of variations in environment are prominent in instrument terminology.

Until very recently no general set of definitions for instrument performance had originated in this country. The comprehensive *Chambers's Technical Dictionary* does not include any terms suitable for describing in an analytical manner the various characteristics of performance, while most of the standard text-books are disappointingly silent on the departures from perfect accuracy with which a large part of the terminology is concerned.

The several committees which prepared British Standards relating to various types of instruments and processes(4–6) found it necessary to define terms in use in sections of the instrument industry, and it became clear that, if only to ensure uniformity in future British Standards, a more general approach to the subject was needed. Accordingly the Instrument Industry Standards Committee of the British Standards Institute approved the appointment of a committee having the task of sorting out and re-defining a number of basic terms which had lost their clarity of meaning. The outcome of this work is a new glossary prepared and published by the British Standards Institution, B.S. 2643,(7) published in December 1955. It is essentially definitive, whereas previous glossaries have often recorded alternative meanings.

A few authors writing on instruments in general have introduced new terms to describe aspects of performance. Schlink(8) has an important paper on the causes and effects of random errors; in this paper it is shown how the performance of an instrument can be analysed by tracing its "hysteresis loop" and how the form of this loop depends on various characteristics which are named and carefully defined. This and other papers by Schlink have been summarized by Pollard.(9) There is also a useful contribution by Trimmer(10) in which the fundamental aspects of instrument performance are considered and definitions offered for the appropriate terms.

This introduction to the literature of terminology is probably far from exhaustive but it does represent the meagre result of a moderately conscientious search.

The main purpose of this article is to consider the definitions of the more important terms and particularly those which have given rise to difficulty and even controversy. To this end the new B.S. 2643 will be taken as a basis for discussion, the other sources previously mentioned being drawn upon for comparisons.

THE DESCRIPTION OF SCALES AND THEIR ESTABLISHMENT

Scale features. Every measuring instrument is required to exhibit the results of its measurements and this is almost always done by means of an index and scale or by imprint on a chart. Several committees of the British Standards Institution and other bodies have worked on scale terminology and the definitions in B.S. 2643 are consistent with their recommendations, so that proper use of the British Standards definitions should avoid confusion. These definitions are, briefly, that a scale is made up of *scale marks* (*graduation mark* and *graduation line* are also accepted) each separated from its neighbour by a distance which is the *scale spacing*. The *scale interval* is "the increment of the measured quantity corresponding to the scale spacing." The notable absentee from the company of these scale attributes is the familiar *graduation*: this term has been returned to the instrument factory, where it resumes its proper function of describin process of setting out a scale.

For the purpose of precise definition of scale length spacing the effective point of the index is said to describ *index path* and a line on the scale itself corresponding t index path is called the *scale base*. The scale base is necessarily the line from which the scale marks sp though since the scale base draws its definition from the i path there is no reason why the index path should no defined so as to make the scale base coincide with one o "construction lines" of the scale if that is desirable particular case. That physical part of a scale lying bet two adjacent scale marks is a *scale division*, and so ano misnomer for the scale mark is put back in its proper p

To describe the whole range of values which a multir instrument can measure, the term *instrument range* is re mended, with *scale range* for each range setting. A *m* *purpose* instrument for measuring, say, current and vo is in effect two instruments for which the instrument ra must obviously be quoted separately.

Strictly speaking the British Standards definition of or instrument range leads to its expression as an alge difference, as so many units of the quantity to be measu this does not indicate at what values the scale begins ends. However, in a note to the definitions it is recomme that the terminal scale values should be quoted. In Am the term *span* is in use for the algebraic difference of ter values, with *range* to show in addition the actual limits

Turning now to the description of the operations ca out on the scale by the instrument maker, the terms of by the British Standards glossary may be introduced by u them to describe some typical sequences of operations

The blank scale plate of a high-class instrument is *calib* or *pointed* with the aid of an instrument of high precisio with a series of standard values of the quantity to be measu such as the "fixed points" of a temperature scale. (*Calibra* is a more general term than *pointing*: *calibration* desc any process for establishing the "scale law" of an instrum but *pointing* means putting the first marks on a blank s plate.)

The process of *graduation* is completed by *dividing* the s and for this the pointing marks are the guides though do not necessarily coincide with any graduation marks.

If the scale plate is not blank but instead is already prov with an arbitrary scale, the instrument has to be *calibr* by relating scale values to known values of the quantity t measured. This is also done if the quantity to which measuring element of the instrument responds is not same as the quantity which the instrument as a who designed to measure. Thus an electric hygrometer may a milliammeter as the measuring element; this meter ha be calibrated by relating its indications with values of rel humidity.

For instruments of lower accuracy it is often possib determine a law of response which will apply with suffi accuracy to all instruments of the same design, especial one or two simple adjustments can be made to indivi instruments to compensate for the effects of manufactu tolerances. In other words the calibration of the instrun is carried out in the course of designing it. Printed s can then be fitted and all that remains to be done is to the index on some *datum mark* (e.g. the *zero mark*) and haps to *range* the instrument to make it conform to predetermined law of response.

In the course of time, errors of indication may creep or there may be scale errors even in a new instrument.

refore, the highest possible accuracy is to be maintained, instrument will sooner or later have to be *verified*. This process similar to that of calibration; the difference is t calibration only provides the data for graduation or for initial relating of scale readings to values of a physical intity, whereas *verification* determines indication errors.

t will be apparent to those who are familiar with instru- nt terminology, and particularly to instrument makers, t the preparation of the new British Standards glossary has olved a good deal of sifting and sorting out of terms; haps, therefore, it will be well to give some consideration the case for accepting these terms as they are now defined the glossary and to the reasons why others should have t their place.

Calibration; Standardization. To those who do not open to be associated with the manufacture or servicing of tain classes of instruments it may come as a surprise to rn that *calibration* and *standardization* are quite widely lerstood to describe processes of adjustment. In some chanical instruments there is an adjustable linkage between sensing element and the index which enables the magni- tion, and even the law of response of the index, to be usted; similarly in electrical instruments series and shunting istances can be adjusted to make the indications accurate within the prescribed limits when a pre-established scale is ed. The quite commonly used general term for these ustments is *calibration*, and in the same habit of language *ndardization* is the particular process of adjusting sensitivity that when the physical quantity being measured changes m minimum to maximum scale value the displacement of index matches the length of the scale.

The American Standard C-42(2) does not hesitate to lorse the use of *calibration* for the process of adjusting an trument's mechanism or auxiliary devices "until it indicates registers correctly within limits." However, a propitiatory te is added: "This definition . . . is to be considered as lecting usage only in the electric meter and instrument lustry and in electric metering practice." It is very under- ndable that electrical engineers would much rather open a meter and make it read correctly than hang a chart of ors on the instrument, but surely alternative methods of toring accuracy deserve separate descriptions. *Adjustment* *ranging*) and *verification* are available and appropriate.

There are two other meanings of *calibration* in the instru- nt world: one is the determination of indication errors; other is the one now advocated, namely, the determination the characteristic relation between values and indications. here a choice between such widely different meanings has be made and the sin of misappropriation avoided, it is en helpful to return to the original usage or even to the inition of the word when employed in non-technical guage. The *Oxford English Dictionary* defines *to calibrate* is: "to determine the calibre of, as of a thermometer tube; graduate a gauge of any kind with allowance for its egularities." Glazebrook's *Dictionary of Applied Physics* scribes the calibration of the bore of a capillary tube tined to carry the scale of a standard mercury-in-glass rmometer. This process consists in measuring the varia- ns in the bore all along its length so that the length of each ision corresponding to equal increments in temperature y be calculated.

t is quite clear from these references that the definition of *ibration* favoured by B.S. 2643 is the one in harmony with original meaning.

The only logical alternative to accepting this usage is to card the word altogether: this course is not without its advocates, but it is, to say the least, a waste of a very good word merely on the grounds that it has been allowed to get out of hand. As Humpty Dumpty said in his discussion of terminology: "The question is which is to be master." (We are, however, on dangerous ground in quoting Humpty Dumpty for it was he, clearly the arch-enemy of terminologists, who also said: "When *I* use a word it means just what I choose it to mean—neither more nor less.")

By the test of most common usage, supported by the dictionaries, *standardization* must retain its right to express some general concept, such as the establishment of standards, rather than suffer appropriation for the description of a fraction of a manufacturing process. Moreover, if the uses of *calibration* and *verification* now put forward are accepted there is no need to consider the lending of *standardization* to the procedures which these terms describe, as has been the practice in some branches of the instrument industry.

Ranging; Adjustment; Setting. Although *calibration* and *standardization* have certainly been used for describing the process of fitting the range of index deflexion to a pre-established scale, this process is also known quite widely as *adjustment* or *ranging*. B.S. 2643 plumps for the latter, perhaps because *adjustment* has an even more general meaning, and might include *setting* to a zero or datum mark.

Verification. There is a strong case for establishing a term to stand in place of *calibration* for the determination of errors of indication, so avoiding a dual meaning for *calibration*. Verification is the word which has been proposed, and it is adopted for the new British Standards glossary. Its use is not intended to be confined to the examination of an instrument for compliance with the limits of error laid down in a specification.

THE DESCRIPTION OF PERFORMANCE

Turning now to the terminology of instrument performance, we find ourselves in rather more difficult country because there are a number of closely allied qualities which need to be distinguished from each other but which cannot be unambiguously described by the inherent meaning of words in common use. Terms have therefore to be allocated to the qualities in a more arbitrary way than was necessary in the case of the processes associated with design and calibration. This is particularly true of the family of terms which describe reproducibility of indication under various conditions of measurement. There is little to choose between *reproducibility*, *repeatability* and *consistency*; *precision* has quite firmly established itself in this company, while *constancy*, *stability*, *drift*, *variation* and *variance* are also wandering about unhappily in the offing.

Sensitiveness; Discrimination; Passiveness. The freedom of an instrument movement from backlash and "stickiness" is clearly an important factor in performance. This quality is generally known as *sensitiveness*; B.S. 2643 calls it *discrimination* to avoid confusion with *sensitivity*. Schlink(8) has proposed the term *passiveness*.

When it comes to defining a quantitative measure of sensitiveness a difficulty arises: the usual definition of its measure is "the smallest change in the quantity measured which produces a perceptible movement of the index." This always leads to a discussion of what is meant by "perceptible"—is it permissible to use, for instance, a high-power magnifying glass to detect the first minute movement of the index? The British Standards glossary recommends that discrimination should be related to the conditions under which the index is observed, while in defining *mobilité*, the

French equivalent of sensitiveness, the *Terminologie*(3) specifies measurement by an average observer using the instrument in the normal conditions of use. However, bearing in mind that the existence of the term recognizes an inability to respond *at all* to a sufficiently small stimulus it appears that any attempt to qualify or define "perceptible" in the sense of admitting some finite deflexion of the index is based on a misconception of the true quality of sensitiveness.

Schlink, in his definition of passiveness, uses a very significant phrase; "the smallest alteration in the quantity to be measured which will produce any change whatever in the indication of the instrument." Defined in this way, passiveness is a perfectly definite quality corresponding to the *dead zone* of an automatic control system. (Schlink's term has incidentally the virtue of giving numerical values which vary in the same sense as that of the quality.) On the other hand, a definition which stipulates that the index displacement shall be visible under normal conditions of use implies the attainment of a finite displacement (by no means vanishingly small for a switchboard instrument) and consequently allows *sensitivity* to intrude upon passiveness.

The failure to separate these two instrumental properties in describing the responsiveness of an instrument may account for the fact that, in the past, what is now known as sensitiveness (discrimination, passiveness) used to be called sensitivity.(3,8) This muddle evidently persists, for Eckman(11) can write: "Usually sensitivity denotes the smallest change in value of a measured variable to which an instrument responds . . ." while acknowledging the existence of the alternative definition. The situation is not improved by the use, in automatic control terminology, of *threshold sensitivity* or *resolution sensitivity* to describe the minimum stimulus required to actuate a control system.

If Schlink's definition (of passiveness) is accepted the difficulty of having to define or allow for rather arbitrary conditions of observation disappears, because until the applied stimulus marks the extent of passiveness by overcoming friction and mechanical slackness or their equivalents, there is *no* response by the index: all that is required of the observer is that he shall be able to detect the onset of index displacement to a sufficient degree of accuracy. The observation of the index with a microscope would not normally lower the value of passiveness indefinitely: it would merely ensure a rather more accurate value (if the instrument had a high sensitivity the effect of using the microscope would be small). On the other hand, the apparent value of the passiveness of such instruments as galvanometers with suspended coils or precision balances is lowered as the acuity of observation is increased; this is reasonable, because the observation of their passiveness may well be beyond the power of the unaided eye.

Sensitivity. Nearly all modern definitions of sensitivity agree in describing it as essentially the value of dL/dQ, where dL is the displacement of the index for a small change dQ in the quantity being measured. This seems, at first sight, to be a straightforward definition but unless the conditions of measurement are properly chosen passiveness or hysteresis may interfere with the measurement. Schlink(8) discovered that the typical index response curve of a mechanical instrument has the form of a hysteresis loop, so that strictly speaking the value of sensitivity depends on how the measured quantity has been varying up to the moment of measurement. However, the slope of the curve relating index deflexion L to measured quantity Q, with Q increasing, would normally give a sufficiently accurate value of sensitivity at any particular point on the scale, though this sensitivity would not necessarily be applicable to the indications of small irregular ch in Q.

The sensitivity of some instruments (such as che balances) is traditionally expressed in the form Q/S milligrams per scale division). This measure may log be termed the *sensitivity reciprocal*.(12)

Accuracy. It is curious that no method of expre *accuracy* itself has come into general use: it is almost al *inaccuracy*, that is, *error*, which is stated. Indeed American Standard C 42(2) actually defines accuracy a number or a quality which defines its limit of er Trimmer(10) suggests that accuracy should be defined qu tatively by the expression $1 - E/Q_m$ where Q_m is the maxi scale value and E the maximum error anywhere withi scale range: the less the error the higher the figure of accu which is as it should be.

Error. Allocation of the plus or minus sign of *indic* (or *instrument*) *error* need cause no difficulty if this err defined, as in effect it is in B.S. 2643, as the difference obta by subtracting algebraically the true value from the indi value. This means that if a thermometer indicates at a true temperature of −10° C, the error is +1° C. some instruments which read above and below a zero units are changed: e.g. amps "charge" and amps "discha In this case B.S. 2643 states that the two parts of the should be regarded as belonging to separate instrumen implication being that the units are positive in both case

Precision. There is a well-established usage of *prec* as a measure of the smallness of random error when re measurements of a fixed quantity are made on a occasion. Yet *precision* undoubtedly has a more ge meaning: it even evokes, in the words of the *Terminolog* "a concept of care, of finish, of quality." (But not French *précision* ≡ accuracy; *fidélité* ≡ precision in narrow sense.) Moreover, the B.S.I. has adopted *prec grade* instead of the old *sub-standard grade* in the classifica of electrical measuring instruments.(4) The fact tha instrument possesses the quality of high precision in narrow sense does not guarantee the accuracy of its in tions, since a systematic error may be present. The que is, does common usage justify the appropriation of *prec* for the description of a quality which while contributin accuracy is not synonymous with it? The British Stand glossary (2643) does not mention *precision* but in its p provides *repeatability* (though the British Standards glos on automatic control(6) has *consistency* for the same th

As a term relating to the smallness of random e *precision* has undoubtedly got a firm hold. Random e can be subjected to statistical analysis if a sufficient nur of readings is taken. Assuming that the normal, or Gauss law of errors is applicable, the distribution of the ran errors about the arithmetic mean of the readings can expressed by a number, which is taken to be a measur precision. It is unfortunate that although, in instrur practice, the *modulus of precision* (h) has been widely ado as the measure, the *standard deviation* (σ) is also someti used. The connexion between the two is $h = 1/\sigma\sqrt{2}$.

It is very probable that the expression *modulus of prec* is responsible for *precision* having acquired this sp meaning of a particular aspect of instrumental accur Schlink(8) obtained, in his investigation of instrume hysteresis, a measure of the *total* range of random error which he proposed the term *variance*. Since this is al term used in statistical analysis (σ^2), Pollard(9) suggested it should be *instrumental variance*.

The co-existence of these various terms relating to ect of random errors might be established on the following sis: *instrumental variance* is an appropriate name for the nifestation of random errors, and *repeatability* for the ality of instrument performance in this respect; a measure *repeatability* is conveniently given by the *modulus of ecision.*

It is perhaps not always appreciated that to obtain a true easure of repeatability or precision at any scale value it is ually necessary to vary the amount of change of the quantity plied to the instrument. This would not apply for balances.

Reproducibility. Having determined the indication errors an instrument and its repeatability the instrument can mediately be used to give measurements of which the curacy will be known within well-defined limits. But what its behaviour in the future? Terms must be used to scribe the capability of the instrument to remain true to calibration for lengthy periods of time.

Changes in accuracy over long periods of time can be amined under two differing sets of conditions. An instru- ent can be verified under uniquely defined conditions of test occasions widely separated in time; the degree of accord tween the mean values of a number of readings taken on ch occasion will then indicate a quality which B.S.2643 fines as *stability.* A quality of rather more practical plication is persistence of accuracy in continuous use, when e instrument is subjected to conditions of service varying thin the specified limits. For this, the new glossary chooses *nstancy.* In assessing *constancy* the variations in indication e to extraneous disturbances such as changes in ambient nperature are allowed to show their effect, whereas they e absent (or are allowed for) in the conditions of test for *ability.* The expression *variation in indication* seemed to l naturally into place in the preceding sentence, and indeed S. 89 gives its blessing to the use of *variation* in the sense which it is used here.

On looking about for support for the use of the various rms of long-term reproducibility proposed in B.S. 2643, or r opposition to them, one is struck by the apparent lack of erest in the terminology of this most important aspect of strument performance. The only term which seems to ve gained currency (but not official status) is *drift.* though the conditions under which this is to be observed ve not been defined, it is probable that *drift* would rrespond to a deficiency in the quality of stability.

The terms *stability* and *constancy* may be said to be positive sense whereas *variation* and *drift* are negative. Since these alities and deficiencies are normally measured in terms of ors the positive attributes tend to be expressed numerically a way more appropriate to negative attributes. There is reason, save that of unfamiliarity, why stability and nstancy should not be formulated in the same way as immer(10) has suggested for accuracy, so that complete bility or constancy would have the numerical value 1 (or)%) and a variation of 5% of maximum scale value would indicated by a stability or constancy figure of 0·95 (95%).

Having regard to the lack of individuality among the terms performance it is not surprising to find that other uses have en found in the field of measurement for words like *roducibility* and *repeatability.* Thus, the Institute of roleum(13) uses these terms to distinguish between varia- ns in the results of tests made "by one operator using one of apparatus" (*repeatability*) and "by different operators ng different sets of apparatus in different locations" *producibility*). The tests are presumably made on identical nples, although this is not stipulated. As it happens, this *eatability* is similar in concept to the *repeatability* of B.S. 2643 (and the defining paragraph is headed "Precision") while the *reproducibility* is comparable with *constancy,* though the instruments, as well as the occasions, are different. The inclusion of the operators as factors contributing to the variation is interesting; but it must be remembered that these definitions apply to tests involving a whole series of operations.

The influence of the observer on the accuracy of the recorded result of an instrumental indication is not to be neglected, and it is right that a term such as *observation error* should be set aside from all connection with instrumental errors. Though the error is to be ascribed to the misjudgment of the observer, the instrument is not necessarily to be absolved from a reciprocal influence, since the design of the index, its position relative to the scale, and the arrangement of the scale marks all affect the accuracy with which the observer can estimate indicated values. Careful attention is now being given to this point in the design of scales, particularly for industrial instruments.

DYNAMIC CHARACTERISTICS

The inertia of the moving parts of instruments and the hysteresis due to various causes give rise to *dynamic errors.* Among the observable characteristics by which some estimate of the dynamic performance can be made are the *response time* (or *settling time*(7)) and the *overshoot.*

The definition of *response time* is necessarily arbitrary because the moment at which an index finally stops moving after an abrupt change in the measured quantity might be very difficult to determine. It is therefore usual to define some small range (related to the accuracy rating) about the final position of rest and to take the time for the index to reach and remain within this region as the response time.(14) An alternative definition involves the time taken to reach a deflexion which is some specified fraction of the final deflexion (ref. 10, p. 154).

ENVOY

Those who wish to pursue this subject in a systematic way may like to have its U.D.C. number: 409.3. "Technical language" shares this number with "Peculiar languages; Secret languages; Thieves' language."

ACKNOWLEDGEMENTS

Although the opinions expressed in this article are not necessarily those of the British Standards Institution Committee which drew up B.S. 2643, I acknowledge with pleasure that my knowledge of the subject was largely acquired through the discussions with my colleagues on that committee in the course of its work. I am also indebted to Mr. A. J. Philpot, Director of the British Scientific Instrument Research Association, for careful criticism of the article during preparation.

REFERENCES

(1) *International Technical Vocabulary* (London: International Electrotechnical Committee, 1938).

(2) *American Standard Definitions of Electrical Terms,* A.S.A. C 42—1941 (New York: American Institute of Electrical Engineers, 1942).

(3) *Rev. Métrol.,* 7 (294), p. 320 (1947).

(4) *Electrical Measuring Instruments*, B.S. 89: 1954.

(5) *Glossary of Terms used in Electrical Engineering*, B.S. 205: Part 3: 1943; *Section 4: Meters and measuring instruments.*

(6) *Glossary of Terms used in Automatic Controlling and Regulating Systems*, B.S. 1523: 1949; *Section 2: Process control.*

(7) *Glossary of Terms relating to the Performance of Measuring Instruments*, B.S. 2643: 1955.

(8) Schlink, F. J. *Bull. Bur. Stand.*, **14** (4), p. 741 (1918–19). (Scientific Paper No. 328.)

(9) Pollard, A. F. C. *Rep. Progr. Phys.*, **10**, p. 272 (1944–45) (London: Physical Society, 1946).

(10) Trimmer, J. D. *Response of Physical Systems*, pp. 173 (New York: John Wiley and Sons, Inc.; Lon Chapman and Hall Ltd., 1950).

(11) Eckman, D. P. *Industrial Instrumentation*, p. 9 York: John Wiley and Sons, Inc.; London: Cha and Hall Ltd., 1950).

(12) *N.P.L. Notes on Applied Science No. 7, Weights precise laboratory weighing*, p. 7 (London: Stationery Office, 1954).

(13) *Standard Methods for Testing Petroleum and its Pro* (15th ed.), p. vi (London: Institute of Petroleum, 1

(14) *American Standard for Electrical Indicating Instrum* A.S.A. C 39.1—1951 (New York: American Ins of Electrical Engineers, 1951).

ORIGINAL CONTRIBUTIONS

A method for rapid analysis of very small gas samples

By H. E. Lewis, M.B., B.Ch., B.Sc., and O. C. J. Lippold, M.B., B.S., Department of Physiology, University College, London

[*Paper first received* 7 *November*, 1955, *and in final form* 17 *January*, 1956]

An apparatus is described for the analysis of small samples of gas (0·1–0·001 ml.). A small bubble of the sample is injected into water in a chamber formed by two horizontal parallel plates. This bubble assumes the shape of a disk, which can be measured, since the volume is then proportional to its cross-sectional area. Convenient methods of optical measurement and recording are described. Analysis is made by the introduction into the chamber of suitable absorbents. Reference is made to some of the uses of this apparatus.

During the course of certain experiments on fatigue and on the physiology of muscular work,⁽¹⁾ it became necessary to make rapid analysis of many small samples of respiratory gases (oxygen, carbon dioxide and nitrogen). The classical techniques tend to be slow and consequently samples had to be stored and the results of analyses were not available during the course of the experiment. An apparatus was accordingly designed to analyse small samples in a short time (about one minute) and had the added advantage that results could be recorded photographically if desired. This meant that accuracy in measurement could be checked later. A preliminary communication was made to the Physiological Society in 1952.⁽²⁾

DESCRIPTION OF APPARATUS

General principle.

The gas sample is injected into acidulated water (in the case of respiratory gases) in a chamber formed by two horizontal parallel plates of glass, 1 mm apart. About 0·01 ml. of gas assumes the form of a thick disk with rounded edges, the volume being proportional to the cross-sectional area which is then accurately measured by means of an optical projection system. A suitable gas absorbent is gently run into the chamber, displacing the water but not flushing out the bubble, which rapidly decreases in volume as the particular constituent gas is absorbed. A second determination is made of the area and the difference expressed as a percentage. Since the chamber is open at one end to the atmosphere, pressure is constant throughout the analysis. The apparatus is designed so that the temperature does not fluctuate (Fig. 1).

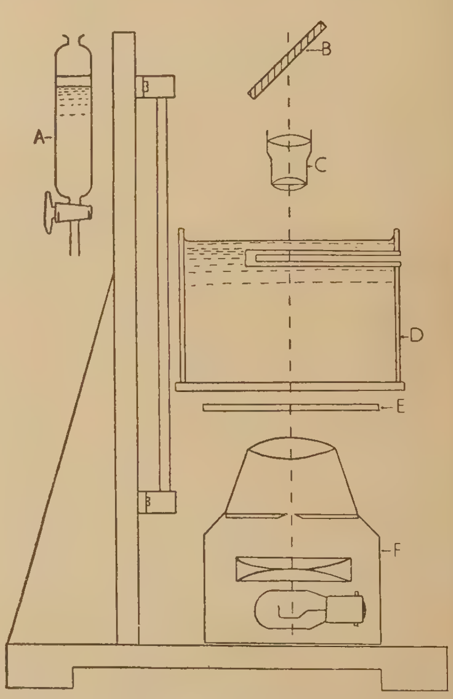
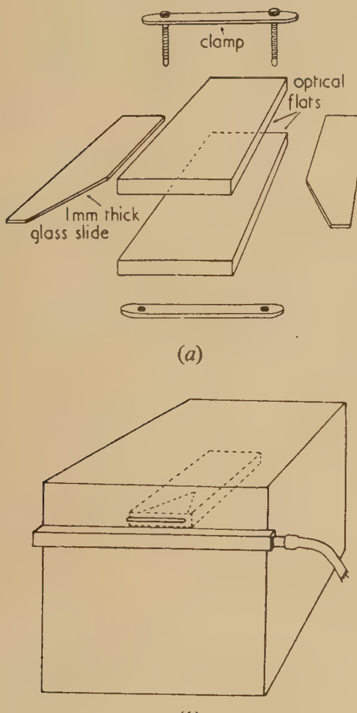


Fig. 1. General arrangement of apparatus for analy of small gas samples

A, fluid reservoirs; *B*, mirror; *C*, projection lens; *D*, chamb in water bath; *E*, heat absorbing glass; *F*, projector.

nstruction of bubble chamber.

he chamber consists of two glass optical flats 10 × 4 cm
arated by two glass slides 1 mm thick, cut to leave a
ngular recess open at one end (see Fig. 2). The glass
embly is clamped together and, because the glass surfaces
optically worked, they form a water-tight unit. The
mber is immersed in a Perspex water bath, with its open
in register with a 1 mm wide slot cut in the side of the
h. A soft rubber gasket provides a water-tight seal.



(a)

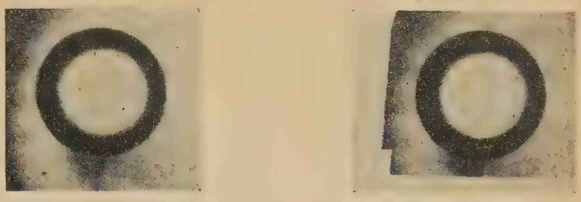
(b)

Fig. 2. (a) Exploded view of chamber.
(b) Chamber in water-bath

he water bath also contains three (or more, if necessary)
rals of glass tubing, each of a volume at least ten times
t of the chamber. These carry the acidulated water and
absorbents from their reservoirs to the chamber and are
essary to ensure that temperature changes do not occur
the chamber upon running-in fluids. The flow is con-
led by a clip (or magnetic valve) in each tube connecting
reservoir with its spiral, while taps on the reservoirs
trol the rate of delivery. The introduction of fluid into
chamber is made through a polythene tube passing into
open end of the chamber. A drain collects the effluent.

ical system.

n enlarged image of the bubble is projected on to a
able screen. For this purpose, parallel light derived from
V, 36 W bulb and condenser system is projected vertically
ough the chamber. A flat of heat absorbent glass (type
. 20 by Chance Bros. Ltd.) is interposed between the
t source and the chamber.
bove the bubble is mounted a 30 mm focal length, fully
ected lens with an aperture of $f/1{\cdot}9$. This casts the
ge of the bubble, a black ring on a white ground, on to
screen where it can be measured directly or photographed
bromide paper (Fig. 3). A surface sputtered aluminium
plane mirror is used to deflect the beam horizontally for convenience.



(a) (b)

Fig. 3. Photograph of bubble: (a) before analysis; (b) after absorption

Measurement.

It is found that the bubble forms a circle, the menicus showing as a thick black ring, the outer margin of which is an accurate representation of its limits. The area enclosed by this outer margin is measured with an Amsler's planimeter, either directly from the screen or on a bromide print. The area must be measured since the bubble is never a true circle, its diameters varying by as much as 1%.

Alternative methods of measurement.

The system lends itself to alternative methods of recording.

(i) Direct measurement.

(ii) Measurement from bromide paper.

(iii) Direct photography of the bubble through the optical flat. In the actual apparatus used, a 16 mm Ciné-Kodak Special camera was mounted above the chamber and enabled the time course of the absorption to be followed to its end point. Alternatively, single frames before and after the reaction could be recorded. This form of the apparatus was also arranged to perform the whole estimation automatically, after the bubble had been introduced. A timing device and relays controlled the various operations of gas absorption and photography in the correct sequence.

(iv) Photoelectric cell methods. By the use of suitable dark ground illumination, arranged so that total internal reflexion occurs, the whole bubble appears black, and light intensity can accordingly be accurately measured. This obviates the need for computing areas.

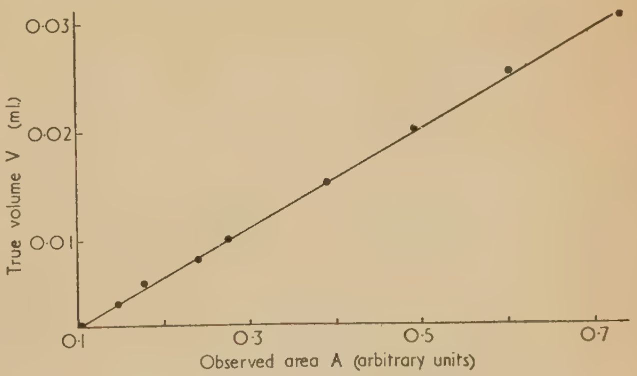


Fig. 4. Calibration curve plotted of

$$V = A - 0{\cdot}38\sqrt{A} + 0{\cdot}075.$$

Points obtained by injecting accurate gas volumes with a micrometer syringe

CALIBRATION

The relationship between observed area and volume is complicated by the fact that the bubble is not a true cylinder, since the sides are formed by the meniscus. This represents a correction factor (of the order of 1% in the case of a bubble of 0·05 ml. volume) which can be determined experimentally by introducing known volumes with a micrometer syringe. The theoretically calculated correction is found to agree closely with these values. The graph of Fig. 4 shows the calibration curve, which over the working range is sensibly linear. Note that when the bubble decreases to a diameter equal to the separation of the plates (namely, becomes a sphere) this relationship does not hold. (See Appendix 1.)

PROCEDURE

(i) *Methods of sampling.*

The gas is collected between mercury seals in polythene tubing. One end of the tube is attached to a micrometer syringe, the other to a shortened hypodermic needle. The sample can easily be expelled into the water of the chamber (the mercury drops rolling away). Samples can be stored for short periods, if necessary, in such tubes between clips at each end. It should be noted in this connexion that rapidly diffusing gases, such as carbon dioxide, will readily penetrate some forms of this tubing.

(ii) *Precautions taken in use.*

(*a*) *Temperature.* Changes in temperature are prevented by the immersion of the reagents and the reaction chamber in the water bath. This, however, is insufficient in itself because of the heating effect of the projector, and for this reason it is necessary to use a heat absorbent glass flat. The volume of washing-out fluid and reagents actually contained in the spirals in the bath must be large compared with the volume of the chamber, so that it will have attained bath temperature before reaching the chamber.

(*b*) *Surface tension.* Distortion of the bubble shape is not a problem when clean optical glass is used for the chamber. Perspex, on the other hand, is not a suitable material, even with the addition of small amounts of wetting agents to the solutions. The effect of differing vapour pressures due to the different solutions does not significantly alter surface tension and may be ignored.

(*c*) *Levelling and centring.* It is essential that the plates of the chamber are truly level to keep the bubble stationary. (Attempts to control it by mechanical means result in distortion.) The Perspex water bath slides as a whole on the levelled Perspex shelf to permit centring for projection.

(*d*) *Premature gas absorption.* Stringent precautions must be taken to remove all traces of absorbent remaining from a previous estimation, because in these small gas volumes reaction takes place extremely rapidly, and at extreme dilution. The difficulty is overcome by a combination of copious flushing and the use of a suitable neutralizing solution (see Appendix 2).

(*e*) *Cleaning.* It is most important that the glass chamber be chemically clean. This is ensured by the following precautions. The chamber should not be allowed to dry out and should be filled with distilled water after use. If precipitates form, immediate removal is necessary. From time to time the chamber must be dismantled for thorc cleaning with chromic acid.

APPLICATIONS OF THE METHOD

A typical physiological application, namely that of analy respiratory gases, is shown in Appendix 2. The method be used in any circumstances where analysis of the gas mix depends on differential absorption by fluids, and for concentrations approaching 100% in the mixture (althc at high percentages the bubble may become too smal measure accurately after absorption, if care is not take ensure that the initial sample is large enough).

ACKNOWLEDGEMENT

We are indebted to the Nuffield Foundation for a gran support of this work.

REFERENCES

(1) KELVIN, P., KOSTIAL, K., LIPPOLD, O. C. J., WHITFIELD, J. *J. Physiol.*, **120**, pp. 42–43*P* (1953)

(2) LEWIS, H. E., and LIPPOLD, O. C. J. *J. Physiol.*, pp. 16–17*P* (1952).

(3) DAHLSTROM, H., and WAHLUND, H. *Scand. J. Clin. Lab. Invest.*, **1**, p. 86 (1949).

APPENDIX 1

A correction factor can be calculated to allow for th that the bubble forms not a true cylinder, but one with e of semi-circular section.

It can be shown that no significant error is introduce the assumption that the meniscus is of semi-circular fc It does not change in form during the analysis.

If A is the area observed, $2t$ the thickness of the chan and V the true volume.

Then $$V = A2t - t^2\sqrt{\pi}.(4-\pi)\sqrt{\left(A+\frac{t^3}{\pi}\right)\left(\frac{10}{3}-\pi\right)}$$

If the distance between the plates is 1 mm, i.e. $2t = 1$, $V = A - 0{\cdot}38\sqrt{A} + 0{\cdot}075$.

APPENDIX 2

Analysis of small samples of respiratory gases

Carbon dioxide is absorbed with a 10% solution of ca potash. Oxygen is absorbed with freshly made up chron chloride solution, prepared after the method of Dahlst and Wahlund.(3) (Being made up in acid solution reagent does not absorb carbon dioxide and thus oxygen be analysed independently if necessary.)

The rinsing fluid is distilled water with 5% sulphuric and methyl red indicator added, to prevent pre-absorptio carbon dioxide. The addition of a small amount of potass permanganate to the rinsing fluid is of advantage in ensu that any residual chromous chloride is oxidized be absorption takes place. When the bubble is introduced the chamber, temperature equilibration occurs alr immediately.

The accuracy of the measurement is better than 0·3 vol % of the mixture when analysing respiratory gases in manner.

A simple differential pulse height analyser

By E. C. Park, A.B.,* Department of Physics, The University of Birmingham

[*Paper received* 22 *August*, 1955]

A single-channel, pulse height analyser is described. Discrimination is by germanium diodes. Only three valves are used: two double triodes in trigger circuits and another in an anti-coincidence arrangement. The analyser will accept positive pulses of shapes normally encountered with scintillation and proportional counters, and has an accuracy comparable to that of other recently reported circuits. The lower level of the discriminator can be varied from 0–60 V and the channel width from 0–20 V. Bias voltages are read directly on a meter. Zero or threshold adjustments are not required. Both differential and integral output pulses are available.

number of differential pulse height analysers have been scribed recently(1–6) which show an improvement in eed, accuracy or versatility over several simpler circuits blished.(7–9)

The primary aim in the design of the circuit described here s been simplicity, both of circuitry and of operation. Yet e analyser will accept a range of such pulse shapes as are rmally associated with scintillation and proportional unters, and accuracy is of the order of that reported for ore complex circuits. There are no zero or threshold justments, the germanium diodes of the discriminator ing less susceptible to contact potential variations than ermionic valves, and the trigger, or flip-flop, circuits being designed that they are negligibly affected by contact tential or small, supply voltage fluctuations.

DETAILS OF APPARATUS

Discriminator. The discriminator is of the biased diode pe.(10–12) Germanium rather than thermionic diodes are ed(13) to reduce capacitance and contact potential variation. e basic circuit, arranged to accept positive pulses, is shown Fig. 1. Diodes D_1 and D_3 are biased: the bias voltage ross D_1 may be set to any value between 0 and 60 V and termines the lower level; the bias across D_3 may be varied m 0 to 20 V and sets the channel width. Diodes D_4, D_5, D_6 and D_7 are primarily d.c. restoring diodes, but diodes D_5 and D_7, which in the quiescent condition conduct a little over 0·1 mA, also provide a low impedance to the capacitive or resistive feed-through of large input pulses until the respective bias levels are crossed. Diodes D_2 and D_6 form an additional discriminator to ensure that such pulses do not trigger the lower level and to balance more nearly the response of the two levels. The circuit is so arranged that the variation of diode characteristics with temperature is partially compensated; in particular, variations in the channel width tend to be balanced out.

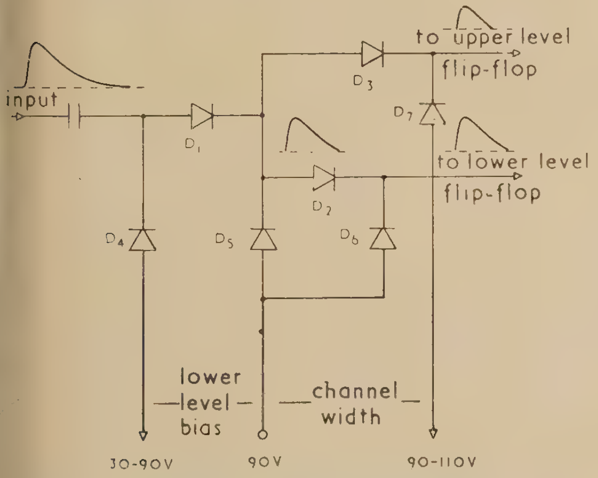


Fig. 1. Arrangement of germanium diodes in the discriminator circuit

Flip-flops. The positive pulses from the discriminator are differentiated before passing to the flip-flop circuits which, as shown in Fig. 2, trigger on negative pulses. In this way the operation of the flip-flops is made independent of pulse height, and the action of both is initiated at the same moment, which is desirable in order that an output pulse from the upper level, when it occurs, should always cancel that from the lower level, regardless of rise time or length of input pulse. This is also advantageous in coincidence measurements since the output pulse is always initiated at (or just after) the peak of the input pulse, and the timing is thus essentially independent of bias setting.

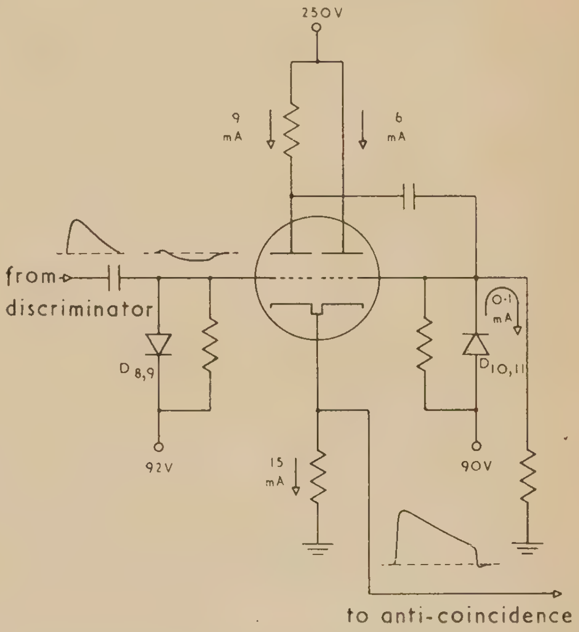


Fig. 2. Flip-flop circuit, including input differentiating network. (Currents shown are for quiescent conditions)

---

* Now at Massachusetts Institute of Technology, Lexington ssachusetts, U.S.A.

The flip-flops are double triode, cathode-coupled univibrators. To reduce triggering errors and to increase the speed of operation, both sides of the valve are maintained in a conducting state in the quiescent condition. Stability is achieved by effectively earthing the feedback grid, so that the positive feedback is spoiled, by means of a conducting germanium diode. This diode also serves as a d.c. restorer to speed the recovery of the flip-flop. Because the bias current is obtained from a point 90 V negative with respect to the diode, small voltage fluctuations or changes in contact potentials have a negligible effect on the stability or threshold.

To trigger the circuit it is necessary to reduce the current through the diode until its slope resistance has risen sufficiently to make the loop gain of the circuit equal to unity. In practice, a current of 0·1 mA is maintained in the stable state, corresponding to a diode slope resistance of 500 to 600 Ω. A decrease of about 0·05 mA is sufficient to raise the resistance to the point (900 to 1000 Ω) where regeneration takes place. This corresponds to a negative pulse on the input grid of the order of 10 mV. This pulse must be "fast," however, in relation to the differentiating time constant in the feedback loop between anode No. 1 and grid No. 2. The flip-flop unit itself is in fact a "velocity" discriminator, thus reducing the chance of response to spurious signals. Furthermore, coupled with the short time constant of the differentiating network in the input circuit, it becomes an "acceleration" discriminator, responding only to the initial, rapid rate of change of fall of a pulse.

Anti-coincidence and output circuit. Positive pulses taken from the cathodes of the two flip-flops to the grid a double triode anti-coincidence circuit; direct cou eliminates any need for d.c. restoration. The lead from cathode of the lower level flip-flop is tapped about 5 V d the cathode resistor so that that side of the anti-coincid valve is normally cut off. It will be turned on, however a pulse arriving alone from the lower level flip-flop and opposite side being turned off thereby, a positive pulse appear on the anode at the differential output. In presence of a pulse from the upper level flip-flop, of the s height and length as that from the lower level, the curre the anti-coincidence valve is not switched, and a sm negative pulse appears at the differential output. A puls either grid will, of course, produce a pulse on the cath and this provides an integral output.

GENERAL

The complete circuit of the analyser is shown in Fi The lower level is set by a "coarse" control, a four-pos switch, and a "fine" control, a potentiometer. These c be replaced by a single, helical potentiometer.

A third section of the "coarse" switch provides pa compensation for the slight variation of current through resistor chain with lower level bias setting and limits resultant variation of channel width to 0·1%. With a s helical potentiometer it would be necessary to connec

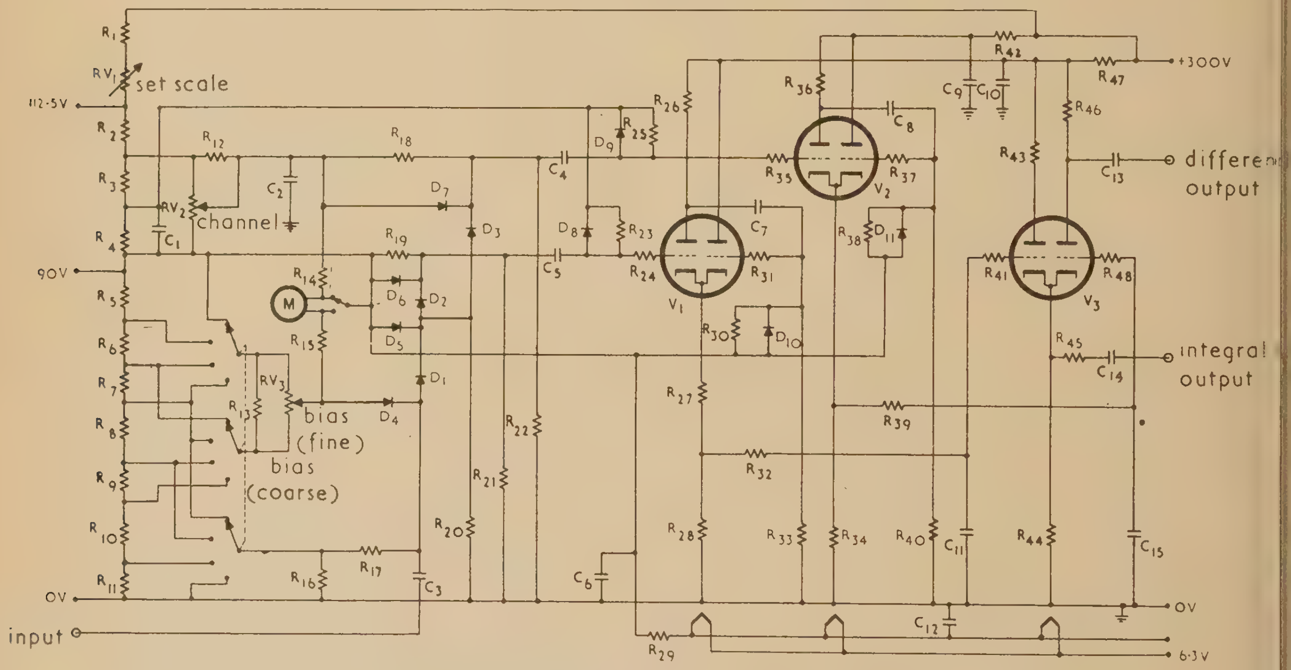


Fig. 3. Circuit diagram of single-channel, pulse height analyser

R_1 = 10 kΩ, 3 W, w.w.
R_2 = 170 Ω
R_3 = 2·7 kΩ, h.s.
R_4 = 330 Ω, h.s.
R_5–R_9 = 1 kΩ, h.s.
R_{10} = 1·2 kΩ, h.s.
R_{11} = 1 kΩ, h.s.
R_{12} = 100 kΩ
R_{13} = 22 kΩ
R_{14} = 100 kΩ, w.w. (selected)
R_{15} = 300 kΩ, w.w. (selected)
R_{16} = 330 kΩ
R_{17} = 220 kΩ
R_{18}, R_{19} = 47 kΩ
R_{20}–R_{22} = 820 kΩ
R_{23} = 12 kΩ

R_{24} = 470 Ω
R_{25} = 12 kΩ
R_{26} = 4·7 kΩ, 1 W, h.s.
R_{27} = 330 Ω
R_{28} = 6 kΩ, 2 W, h.s.
R_{29} = 470 kΩ
R_{30} = 15 kΩ, h.s. (selected)
R_{31} = 470 Ω
R_{32} = 15 kΩ
R_{33} = 820 kΩ, h.s.
R_{34} = 6 kΩ, 2 W, h.s.
R_{35} = 470 Ω
R_{36} = 4·7 kΩ, 1 W, h.s.
R_{37} = 470 Ω
R_{38} = 15 kΩ, h.s. (selected)
R_{39} = 15 kΩ

R_{40} = 820 kΩ, h.s.
R_{41} = 470 Ω
R_{42} = 3 kΩ, 2 W
R_{43} = 2·7 kΩ
R_{44} = 10 kΩ, 2 W
R_{45} = 680 Ω
R_{46} = 2·7 kΩ
R_{47} = 2 kΩ, 3 W
R_{48} = 470 Ω

RV_1 = 5 kΩ, 2 W, w.w.
RV_2 = 2·5 kΩ, w.w.
RV_3 = 5 kΩ, w.w.

C_1–C_3 = 0·01 μF

C_4, C_5 = 17 pF
C_6 = 0·25 μF
C_7, C_8 = 100 pF (selected)
C_9, C_{10} = 0·25 μF
C_{11} = 22 pF
C_{12}–C_{14} = 0·01 μF
C_{15} = 22 pF

V_1–V_3 = ECC91

D_1 = CG4
D_2 = CG1
D_3, D_4 = CG4
D_5–D_{11} = CG1

M = 200 μA

kΩ resistor R_{17}, which provides sufficient current to allow the leakage through diode D_1, to earth; and in this case, ng a 0–500 μA meter with the appropriate 120 kΩ multi- er, the corresponding maximum channel variation should 0·3%.

oints are provided at earth, 90 V and 112·5 V for the nexion of batteries to stabilize the bias levels against pply voltage fluctuations, if necessary.

n construction the discriminator diodes should be grouped ether and separated as much as possible from the rest of circuit to minimize the effect of temperature variations. e diode, D_1, should be selected for a high stable back istance at 60 V: this resistance should be greater than kΩ over the ambient temperature range.

Care should be taken to keep the upper level flip-flop lated from both the lower level and the output circuits in ler to prevent spurious triggering of the first. For the same son, high-frequency filters are inserted between the flip- ps and the anti-coincidence circuit. Flip-flop components uld be selected to give equal time constants; and the bilizing diodes should be mounted away from any heat nerating elements. The stability of the flip-flops may be reased by increasing the value of the current through the bilizing diodes, D_{10} and D_{11}; and, correspondingly, the nsitivity may be increased by decreasing this value.

PERFORMANCE

The circuit can be used to sort pulses of 0–60 V in height us channel width of 0–20 V). Input pulses should generally t exceed 80 V because of the back voltage limitation of the rmanium diodes used. A meter indicates the bias voltages ectly, but the lower level and channel thresholds of about 4 and 0·05 V, respectively, will be in addition to the read- gs. These thresholds, which depend primarily on the aracteristics of the discriminator diodes, should remain nsibly constant, however: a temperature rise of 25° C was und to produce a change in the lower level and channel resholds of only 0·03 V and less than 0·01 V, respectively.

Since the input circuit incorporates a d.c. restorer, it is portant that input pulses should have a negligible over- oot; otherwise the tail of the overshoot may give rise to a sitive bias on the discriminator side of the input condenser, ectively decreasing the lower level bias. If necessary, the ects of the internal d.c. restorer can be nullified by placing diode in series with the input.

For proper functioning of the circuit, input pulses must be om a low impedance source (such as a cathode follower) d, in addition to having no appreciable overshoot, must isfy two requirements as to shape: they must have a fficient width to allow the differentiating condensers to arge; and they must have an initial rate of fall great enough trigger the flip-flop units. While delay-line shaped pulses e obviously ideal, the circuit has been designed primarily use with resistance-capacitance shaped pulses.

For the circuit given, the charging time constant is of the der of 0·03 μs. This puts a lower limit on the length of lses to which the discriminator will respond. Experi- entally it was found that with a resistance-capacitance- aped pulse, having a rise time of 0·15 μs (10–90%) and a cay time constant of 0·7 μs, the variation in effective width a 1 V channel over the lower level bias range is less than 2%, the included limit of accuracy of the test procedure ing ±1%. The sorting of shorter pulses was not attempted t for results of a similar accuracy would presumably require delay line shaping of the pulses or the insertion of cathode followers between the discriminators and the differentiating circuits.

The second requirement, concerning the rate of fall of the pulse, effectively sets an upper limit to the decay time of acceptable pulses. The differentiating circuits and the flip-flop coupling circuits both involve short time constants so that for the circuit values shown in Fig. 3 an "initial" rate of fall of about 0·05 V/μs or greater is required to trigger the flip-flops. The duration of the "initial" period is determined by the flip-flop coupling time constant, and the minimum rate of fall by the differentiating time constant; these are, for the values given, approximately 0·5 and 0·2 μs respectively.

The pulse length of the flip-flops, as determined by the coupling time constant, provides a fixed dead time(14) of, in this case, about 5 μs, and this prevents the acceptance of a pulse arriving on the tail of another which has already triggered the circuit. The dead time of the upper level should be made equal to (or just less than) that of the lower level, so that the lower will not normally become sensitive before the upper. The possibility of a spurious count resulting from the recovery of the flip-flop units from one pulse during the presence of a second, closely following pulse, is minimized by two factors: only the first few volts and the first few tenths of a microsecond of the fall of any pulse can be effective in triggering the flip-flops; moreover, if the pulse starts to fall before the recovery of the flip-flops, the signal on the input grids will generally out-run the decaying voltage on the feedback grids, thus delaying recovery until the sensitive region of the new pulse has passed.

Although the analyser, with time constants as shown, is suitable for sorting pulses of about 0·5 to 10 μs in length, these time constants have been chosen specifically for resistance-capacitance shaped pulses of approximately 1 μs decay time. For minimum dead time together with optimum response and rejection of spurious pulses, the time constants should be adjusted proportionately to suit the length and shape of the pulses to be measured.

A 20 V positive pulse is produced at the differential output, but connexion to the other anode of the anti-coincidence circuit will supply a negative pulse if required. Only positive pulses are normally available at the integral output, 10 V for input pulses lying within the channel and 15 V for those over the upper level. If necessary, a negative pulse could be obtained by inserting a 1 kΩ load resistor in the free anode of the lower level flip-flop.

CONCLUSION

A single-channel pulse height analyser has been described which requires only three valves: simplification has resulted from the use of a germanium diode discriminator in conjunction with a sensitive trigger circuit. A useful accuracy has been achieved without recourse to threshold adjustments or a wide-band "window amplifier."

The analyser has performed satisfactorily for over two years. A number of earlier models have been in use for four years.

REFERENCES

(1) Elmore, W. C., and Sands, M. *Electronics*, p. 235 (New York: McGraw-Hill Book Co. Inc., 1949.)

(2) Eppstein, J. S. *J. Sci. Instrum.*, **28**, p. 41 (1951).

(3) Francis, J. E., Bell, P. R., and Gundlach, J. C. *Rev. Sci. Instrum.*, **22**, p. 133 (1951).

(4) Fairstein, E., and Porter, F. M. *Rev. Sci. Instrum.*, **23**, p. 650 (1952).
(5) Johnstone, C. W. *Nucleonics*, **11** (1), p. 36 (1953).
(6) Farley, F. J. M. *J. Sci. Instrum.*, **31**, p. 241 (1954).
(7) Roberts, A. *Rev. Sci. Instrum.*, **11**, p. 44 (1940).
(8) Pringle, R. W., Roulston, K. I., and Taylor, H. W. *Rev. Sci. Instrum.*, **21**, p. 216 (1950).
(9) Valladas, G., and Thénard, J. *J. Phys. Radium*, **11**, p. 501 (1950).
(10) Westcott, C. H., and Hanna, G. C. *Rev. Sci. Instr* **20**, p. 181 (1949).
(11) Moody, N. F., Battell, W. J., Howell, W. D., Taplin, R. H. *Rev. Sci. Instrum.*, **22**, p. 551 (1
(12) Van Rennes, A. B. *Nucleonics*, **10** (7), p. 20 (1951
(13) Parsons, J. H. *Proc. Inst. Radio Engrs*, **37**, p. (1949).
(14) Cooke-Yarborough, E. H. *J. Sci. Instrum.*, **26**, p (1949).

A sensitive and stable nuclear induction head

By E. A. Richards, B.Sc., G. Phillips, M.Sc., and W. K. Campe, A.M.I.E.E., Signals Research and Development Establishment, Christchurch, Hants

[*Paper received* 16 *February*, 1956]

Details are given of the construction and performance of a "crossed coil" induction head, for the detection of nuclear magnetic resonance in $0{\cdot}1\ \text{cm}^3$ specimens, in which the condition of maximum sensitivity is achieved through the operation of a single manual control. The simple method of construction provides, at the optimum setting, a decoupling of 80 dB between the coils which remains constant to within 0·4 dB over a period of a week.

In the detection of nuclear magnetic resonance by the induction method of Bloch,(1) the specimen under examination is situated at the centre of two coils, the axes of which are mutually perpendicular. One coil closely surrounds the specimen and serves to pick up the small changes in flux produced by the precession of the nuclei at resonance. The other coil is supplied with radio-frequency energy, and is responsible for the excitation of the nuclei.

Since, at resonance, the electromotive force at the inner coil due to the specimen is of the same frequency as the exciting field, it becomes necessary to secure a low value of direct leakage between the coils if a satisfactory detection of the nuclear induction is to be obtained. Leakage is reduced in the first instance by orienting the coils as nearly at right angles to each other as possible; but owing to the practical difficulties involved in achieving this with sufficient accuracy (and because of the additional unbalance caused by small winding asymmetries), the residual leakage is usually minimized by introducing eddy-current elements into the exciting field so that a controlled amount of distortion of the radio-frequency flux in the neighbourhood of the pick-up coil can be obtained.

The high degree of decoupling required results in the magnitude of the leakage being very sensitively dependent both on the displacement of the flux-steering elements and on the relative positions of the coils, and, in consequence, great difficulty is often experienced in obtaining a minimum which remains consistent in the face of minor shocks and the effects of local temperature variations. Trouble is particularly noticeable in this respect when the system is housed in a fabricated box structure, where the operation of one control can cause an unintentional movement of another through a degree of flexing at the corners or walls.

In the induction head to be described, the weaknesses associated with the latter form of construction are avoided by mounting the coils rigidly in a chassis prepared from a solid metal prism. The resulting assembly provides a system of exceptional mechanical and electrical stability which may be delicately adjusted to the conditions of minimum leakage by means of a single manual control.

CONSTRUCTIONAL DETAILS

The complete induction head is illustrated in Fig. 1. main body of the assembly is fashioned from a solid rec gular prism of brass 6 × 4 × $1\frac{3}{4}$ in. of which the top forms a lid to the $1\frac{1}{2}$ in. diameter chamber enclosing pick-up coil.

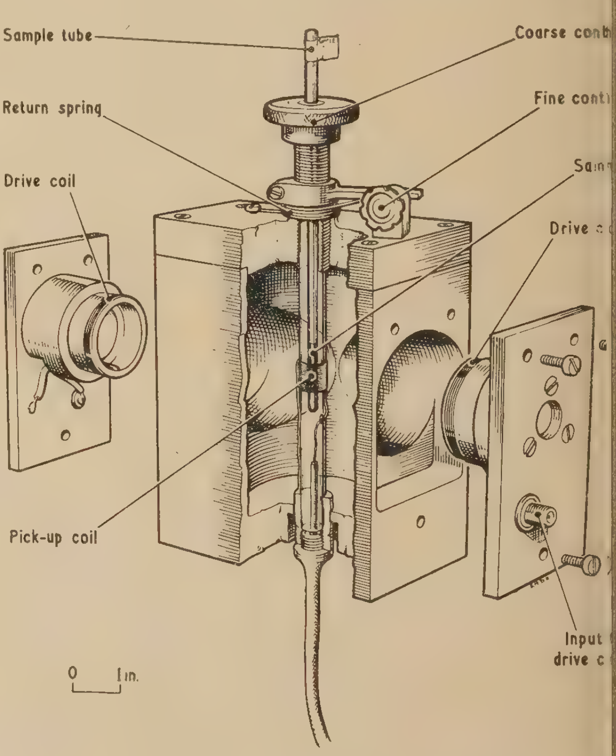


Fig. 1. Details of induction head assembly

The drive coils, which are in the Helmholtz arrangem both consist of four turns of 20 s.w.g. enamelled copper ınd on separate 1¼ in. diameter formers of Perspex, and located axially, in a 1½ in. diameter clearance hole chined centrally through the prism perpendicular to the s of the pick-up coil, by means of the ¼ in. brass end-tes to which the formers are attached. Two separate uts to the drive coils are provided, the innermost ter-nations of the coils being earthed, and the radio-frequency ver, derived from a balanced transmitter, is fed to these lengths of screened cable.

The pick-up coil, which consists of twenty turns of 26 s.w.g. melled copper wire wound at the centre of a straight length glass tubing, uniformly ground to give an outer diameter approximately ⅜ in., is cemented in place with a thin coat Durofix (this adhesive was found to have practically no ct on the *Q* value of the coil, whereas previously a marked nping had been observed with the use of shellac varnish). small hole is drilled in the glass former, approximately ı. from the lower end of the winding, in order to take a d down the centre of the former to the inner conductor the radio-frequency cable feeding into the receiver; the ner end of the winding is taken directly down the outside the former to a brass bush cemented at the base of the mer with Araldite. This bush serves to provide both an ctrical earthing contact with the housing and a bearing the required rotational movement of the pick-up coil.

The sample itself is contained in a length of sealed glass ɔing (¼ in. outer diameter) which can be introduced into centre of the pick-up coil through the top of the coil-rmer *via* a clearance hole in the coarse control knob. This ob connects with a threaded brass sleeve cemented over top end of the coil-former, and serves to move the pick- coil into the region of the radio-frequency drive field ving a minimum direct leakage. A further control, pro-ding a fine adjustment to the orientation of the pick-up il, is afforded by a 2 B.A. screw which bears on the arm tending from the threaded sleeve. This screw is located a lug fixed to the top of the housing and is operated when ly a small degree of orientation is desired. Firm contact maintained between the arm and the screw by means of a osphor-bronze return-spring which is coiled round the eve and anchored at the arm and the housing. For a tation of the coil beyond the limits of the fine control rew, the arm may be unclamped from the sleeve and the arse control operated freely.

It is important to mention, in passing, that no ferromagnetic aterials are used in any of the construction because of the ssibility of distorting the field near and in the magnet gap ıen the head is situated between the poles of a magnet.

OPERATION AND PERFORMANCE OF HEAD

In the present work, the static magnetic field required for e polarization of the sample is provided by an electro-agnet, possessing 4 in. diameter shaped pole pieces and a ın. gap, the field intensity of which can be adjusted by ntrol of the energizing current. For the detection of oton resonance a field of 2350 G is used.

The radio-frequency supply to the drive coils is obtained om a balanced crystal-controlled transmitter working at a equency of 10·00 Mc/s, which, under conditions of optimum ıtput, is capable of delivering up to 100 V r.m.s. at the out-t terminals. Upon connexion of this circuit to the drive ils with two 2 ft lengths of screened cable (Uniradio type 32), thermocouple measurement of the current flow in the coils owed that a maximum field of 1·4 G (peak-to-peak) was ailable at the centre of the Helmholtz pair.

The unloaded *Q* of the present pick-up coil is 120, and, therefore, with a water sample of 0·1 cm^3 volume, an induction of the order of 0·1 mV becomes potentially available(2) due to proton resonance.

Thus, for such signals, a modest amplification only is needed, and in the receiver constructed for this purpose, the circuit consisted of a single tuned radio-frequency stage (approximately 200 gain), followed by a crystal diode detector and one low-frequency stage. The output was sufficient to provide a full-screen presentation on an oscilloscope when the internal amplifiers of the latter were used. In making measurements of the direct leakage from the drive coils to the pick-up coil it was found convenient to connect a calibrated d.c. meter across the diode detector of the receiver.

Although, in the original design, provision was made for finally backing-off the leakage by means of a pair of flux-steering "paddles" similar to those used by Weaver,(3) it was found that an exceptionally fine balance could be obtained by orientation of the pick-up coil alone. More surprisingly, it was discovered that this balance could not be bettered by any subsequent adjustments of the paddles. The cause of this quite unexpected behaviour is attributed to the accurate centring of the pick-up coil relative to the drive coils, and also to the fact that a neutralizing effect occurs through currents being induced in the two leads to the pick-up coil which run down the former diametrically opposite each other for a distance of about ½ in. As no further improvement in the decoupling could be achieved with the paddles, they were discarded.

Upon rotation of the pick-up coil one notices that a number of leakage minima are traversed as the plane of the coil-leads coincides with the axis of the drive field. These are of decreasing amplitude as the pick-up coil is moved from either side towards a position near the centre. Here it is possible to obtain a leakage minimum suitable for the detection of nuclear signals. The extent of the decoupling obtained at the latter point can be seen in Fig. 2 where, at the orientation of optimum neutralization, the leakage-voltage at the pick-up coil is approximately 80 dB smaller than the terminal-voltage at the transmitter. The delicacy of adjustment will be appreciated when it is noted that the leakage is nearly fifteen times greater when the pick-up coil is rotated ±½° from the minimum position.

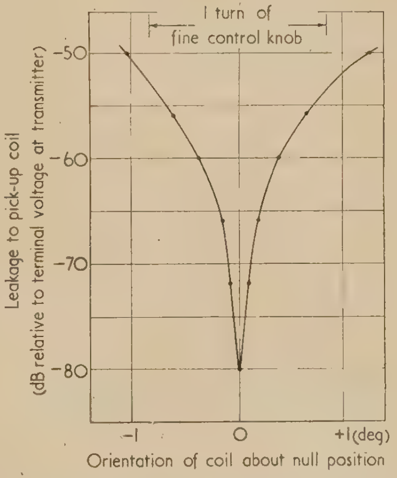


Fig. 2. Effect of pick-up coil orientation on radio-frequency leakage from drive coils

This sensitivity is, of course, of no great advantage if the coil cannot be maintained in the same position over long periods against minor shocks, such as that experienced by movement of the sample tube, and variations in room temperature. Periodic observations were therefore made on the leakage voltage for just over one week, in order to determine the extent of the variation in the minimum, and during this time the sample was carefully removed and replaced a number of times. With the drive kept constant at 100 V r.m.s., the maximum displacement from the smallest leakage value of 10 mV was noted to be less than +0·5 mV (i.e. a change of 0·4 dB). During a single day the variation was rarely ever more than 0·1 mV.

Proton resonance signals detected with the induction head adjusted to the above conditions are shown in Fig. 3 where the sample used is a solution of ferric nitrate (6·8 × 10^{19} ions/cm^3) of volume 0·1 cm^3. It is to be emphasized that the field in the gap of the electromagnet employed in these observations was of relatively low uniformity (approximately 1 part in 10^3 over a volume of 1 cm^3 at the centre of the gap) and the signals obtained are therefore of rather low resolution.

The first trace, Fig. 3(*a*), is a presentation obtained with a radio-frequency drive-field intensity of 1·4 G (peak-to- and saturation of the sample is shown by an almost com absence of "wiggles."(4) In Fig. 3(*b*), where a field inte of 0·4 G has been used, the magnitude of the signals ap diminished, but the "wiggles" associated with the sm precessing fields begin to show themselves. Finally whilst using the smaller radio-frequency field, one ro the pick-up coil slightly so that the leakage is increase amplitude and changed in phase, the trace shown in Fig. is obtained, in which the signal appears either totally a or totally below the zero line, depending upon the sen rotation, to give a display similar to that obtained with absorption method(5) of detection. The receiver gain in last trace has been increased slightly to show the "wig more clearly.

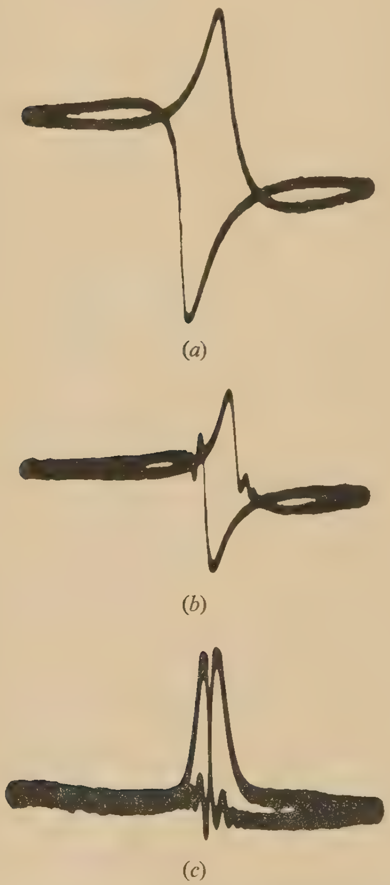

(*a*)
(*b*)
(*c*)

Fig. 3. Oscillograms of proton resonance observed with induction head

Magnet field modulation (50 c/s): full scale = 3·4 G; sample = 0·1 cm^3 water; magnet field 2350 G; drive-field frequency = 10·00 Mc/s.

(*a*) Radio-frequency drive-field intensity, 1·4 G (peak-to-peak).
(*b*) Radio-frequency drive-field intensity, 0·4 G (peak-to-peak).
(*c*) Radio-frequency drive-field intensity, 0·4 G (peak-to-peak).
Pick-up coil rotated slightly off balance (increased receiver gain).

CONCLUSION

The induction head described is extremely simple t up and maintain at the conditions necessary for opti "signal/noise" in the detection of nuclear resonance ph mena. The signal-frequency leakage to the pick-up c brought to a very small fraction of the energy applied di to the drive coils, by the operation of a single manual con a feature of considerable advantage in that it not only en ease of adjustment without the use of auxiliary flux-ste paddles, but also that it provides exceptional stability long periods.

More satisfactory traces than those shown in Fig. 3 sh be obtainable using a magnet of higher field uniformity, it is quite possible that the overall efficiency of the indu head itself may be improved upon in some ways. For insta in the present arrangement, using normal thickness g tubing, the effective sample volume is just 0·1 cm^3, whe the volume encircled by the pick-up coil is nearly 0·8 c Assuming that the static magnet field is highly uniform the pick-up coil, a considerable increase in nuclear f linkage is available by utilizing more completely the volume. This can be accomplished by employing tubin thinner wall and/or containing the sample directly inside coil-former.

Further improvement may be obtained by attention to coil design. It can be shown that the induction in the pick coil is proportional to the product of N and Q (where N an represent the number of turns and the amplification fa of the coil respectively) and, as an example, a rewind of previously existing coil produced a seven-fold increase this value, merely by diminishing the wire gauge and increas the number of turns. Also important are the length losses of the screened cable connecting the coil with receiver circuit, since these factors are bound up with above value of Q. To minimize the lead lengths, the f stage and detector of the receiver may conceivably contained within the head itself.

REFERENCES

(1) Bloch. *Phys. Rev.*, **70**, p. 460 (1946).
(2) Bloch. *Phys. Rev.*, **70**, p. 476 (1946).
(3) Weaver. *Phys. Rev.*, **89**, p. 923 (1953).
(4) Jacobsohn and Wangsness. *Phys. Rev.*, **73**, p. (1948).
(5) Purcell, Torrey and Pound. *Phys. Rev.*, **69**, p. (1946).

A constant-volume, membrane, interferometric microrespirometer

By B. M. Turner, Turner Lighter Spares and Components Ltd., Hendon, London, N.W.4

[*Paper first received* 12 *October*, 1955, *and in final form* 23 *January*, 1956]

Gas exchange in the 7–10 mμl. air film enclosed between a cover slip and the end of a capillary tube closed by a thin collodion membrane is measured by the external pressure required to restore the membrane to its constant volume position parallel to the slip. Membrane displacement is observed by two-beam reflexion monochromatic interferometry. The membrane separates each chamber from a common manifold leading through a central spherical joint to a conventional Warburg manometer. Rotation about the joint brings each chamber successively under the microscope. No membrane calibration is required. The capillaries are embedded vertically in an aluminium block for temperature uniformity. Preliminary results show a sensitivity of 1–10 μμl.

PRINCIPLE

tead of measuring minute respiratory exchanges by ovement of a liquid drop along a calibrated capillary be,(1–4) or by the pressure required to restore the piratory chamber it encloses to constant volume,(5–9) a n membrane is employed and its displacement relative to lat surface is observed by two- or multiple-beam inter- ometry.

The fixed point of constant volume is the position in which membrane is parallel with the reference flat. This point unique in that the interference fringe width increases ddenly and the direction of fringe movement reverses, as convex (or concave) membrane becomes successively plane d then concave (or convex). It is also the point of maximum nsitivity of the interference system.

The thin membrane separates the reaction chamber from a mmon manifold leading to a conventional Warburg mano- ter containing Brodie's solution. The pressure required to ng the reaction chamber back to constant volume is then dily measured without calibrating the membrane.

OPTICAL SYSTEM

Localized and non-localized transmission and reflexion nges were tried.(10, 11) The most convenient system seemed be two-beam reflexion fringes without collimating lens, licating approximately 100 Å membrane displacement ng mercury green monochromatic light (Ilford gelatin er 807 and ultra-violet light absorber Q 805). For greater nsitivity, multiple-beam interferometry, and possibly trans- ssion-like reflexion multiple-beam interferometry might be ployed to measure displacements of 10 Å,(12, 13) or Dyson(14) or Baker(15) interferometric microscope used.

APPARATUS

The reaction chambers *A* (Fig. 1) were contained between ground ends of Pyrex capillary tube *B* (2–2·5 cm long, nm bore, 6 mm outer diameter) closed with a thin collodion mbrane *C*, and a piece of No. 3 cover slip *D* held in place B.D.H. lubricant P. 173172 *E*. Displacement of the lodion membrane was observed interferometrically, the ver slip acting as reference flat.

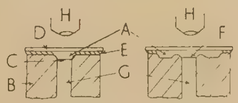


Fig. 1. Vertical section of reaction chambers

The collodion membranes could be most simply prepared delivering one to two drops of collodion solution on to the 5 cm diameter distilled water surface in a beaker covered with a watch glass.(16) The edge of the film was pushed aside and a Pyrex capillary tube immersed, brought under a uniform area and lifted out vertically. Excess film was trimmed with a razor blade. Waxing or siliconing the capillary bore prevented water entering and breaking the membrane.

More uniform films were prepared by a simplification of Brattgard and Hallen's method for preparing thin collodion electron microscope supports.(17) The Pyrex tubes were loosely held (with the aid of 2 mm thick rings cut from rubber pressure tubing) in eighteen holes 0·75 cm diameter drilled in a 10 cm diameter aluminium sheet. Projecting from this, four upwardly directed arms covered with rubber tubing prevented slipping and contained collodion solution to saturate the atmosphere. The sheet was placed horizontally in a 17·5 cm funnel closed with rubber tubing and a Hoffmann screw clip. An aluminium plate covering the funnel was drilled to admit connexions to a calcium chloride drying tube and a suction pump. A third central hole was closed with a rubber stopper.

The funnel was filled to approximately 1 cm above the aluminium holder. Collodion (by Griffin and Tatlock, Ltd.): amyl acetate, 1 : 3 (by volume) mixtures containing 1% (by volume) butyl phthalate were usually used. It was delivered carefully through the central hole, holding the pipette vertically and near the water surface. The surface was cleaned by discarding the first few films. If the distilled water was below room temperature, moisture condensation gave weak, opaque membranes.

After preliminary drying with a current of air, the solidified membrane was lowered on to the capillary tubes by slowly draining away the distilled water through the funnel stem. The collodion was cut around each tube, and the holder of membrane-covered Pyrex tubes dried in a vacuum dessicator over silica gel.

Reaction chamber volume could be varied according to the capillary tube bore, rounding of the bore ends and recession of the membranes on drying. Larger chambers were prepared by fire-polishing the capillary tube ends in a blow flame. This gave, with membrane and cover-slip, a thin central interference system *F* surrounded by a reaction chamber *A*.

The capillary tubes were arranged vertically, chambers uppermost, in eighteen bevelled holes *I* (Fig. 2) bored peripherally in a 2 in. diameter × ¾ in. thick aluminium block *J* bolted to a 2⅜ in. diameter × 2 in. thick lower block *K*. The tubes were connected by radially disposed glass capillary and rubber pressure tubing *L* to 1 mm bore glass capillary stopcocks *M* and a circular manifold *N* held by wire to a 9 in. diameter aluminium saucepan *O* with the bottom partly cut away.

The arrangement was suspended partially immersed in a circular bath by a central Duralumin tube *P* ending in a clamped ball-bearing race Q permitting free rotation. The manifold tube R passed through the central hole of the aluminium blocks and Duralumin tube, and was connected to the manometer by a spherical ground glass joint S (by Quickfit and Quartz Ltd.) allowing rotation without strain.

A microscope H fitted with a 16 mm objective and ×10 eyepiece, and a Beck vertical illuminator, was clamped from the wall of the bath over the central assembly, so that each reaction chamber or the thermobarometer could be brought successively into view by rotation, the Warburg manometer brought to the last reading of this chamber, the appropriate stopcock opened to connect the capillary bore at G to the manifold and the external pressure adjusted until the interferometrically observed null point was attained.

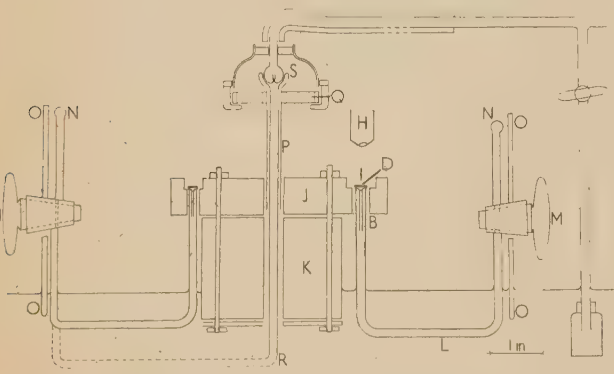


Fig. 2. Vertical section of microrespirometer. (Warburg manometer, bath and optical arrangement not shown)

The thermostatically controlled bath was 15 in. inner diameter and 11 in. deep, double-walled and kapoc-lagged at sides and base. A circular bath gives excellent temperature control with no "dead corners."(18) Embedding the reaction chambers compactly in the partially immersed aluminium blocks held the temperature of the reaction vessels uniform. Additional uniformity was given by surrounding part of the manifold within the outer aluminium walls.

Preliminary tests have been carried out with simple chemical reactions involving gas exchange. B.D.H. lubricant was sparingly applied to the rim of the capillary tube ends by holding at an angle in contact with a horizontal lubricated glass plate and rotating. A microdrop of known volume of 0·1 N sodium carbonate and one containing excess of dilute sulphuric acid were delivered close together by a micromanipulator, in the peripheral reaction chamber A, and the cover slip carefully applied with a little pressure. Proper humidity control was maintained during delivery.

Attempts were made to mix the drops by fusing a glass capillary rod radially on to the cover slip or, more simply, to deliver the second drop (excess acid) on to the cover slip itself and, in either case, to mix by rotation of the slip. To avoid this movement, the solutions were coalesced by magnetically displacing a glass-coated fine iron wire placed in the second drop, and the carbon dioxide evolution measured.

The chamber constant could most conveniently be calculated from the cross-section and plan dimensions measured microscopically with a calibrated eyepiece graticule. However, irregularities in the membrane, bore, and area of the lubricated capillary end, made this inaccurate for smaller chambers. Direct calibration with carbon dioxide evolution (sodium carbonate and acid) seemed the most reliable.

The small chamber volume and high sensitivity o interferometrically observed thin membrane combine to a thousandfold increase in sensitivity over the capillary c In preliminary experiments, using 1 mm bore capillaries g 7–10 mμl. chambers, 1–10 $\mu\mu$l. could be measured, comp with capillary diver volumes of 40–100 mμl. and sensi 2–20 mμl.(8)

The method also possesses other advantages:

(1) avoidance of hysteresis of a liquid indicator dropl carbon dioxide leakage;
(2) no calibration of a capillary tube required;
(3) rapid handling and observation by placing rea system on a surface instead of in a capillary tube;
(4) the optical system is readily available and does require critical optical setting;
(5) inherently easier than a suspended diver to com with other techniques.

A description of the delivery and volume determinati microscopic drops will be published shortly. Further de of the microrespirometer will also be published in conne with the respiration of single cells.

ACKNOWLEDGEMENTS

The author thanks Dr. J. Stern of the Fountain Hosp London, for his advice and encouragement, and also g fully acknowledges the assistance of his wife, Mrs. M Turner, in preparing the manuscript.

REFERENCES

(1) Gerard, R. W., and Hartline, H. K. *J. Cell. C Physiol.*, **4**, p. 141 (1934).
(2) Cunningham, B., and Kirk, P. L. *J. Cell. C Physiol.*, **20**, p. 119 (1942).
(3) Stern, K. G., and Kirk, P. L. *J. Gen. Physiol* p. 135 (1940); **25**, p. 663 (1942); **31**, p. 239 (1948
(4) Tuft, P. *J. Exper. Biol.*, **27**, p. 334 (1950).
(5) Linderstrøm-Lang, K. *Nature* [*London*], **140**, p. (1937).
(6) Holter, H. *C.R. Trav. Lab. Carlsberg, Ser. Chim.*, p. 399 (1943).
(7) Boell, E. J., Needham, J., and Rogers, V. *Proc. Soc. B*, **127**, p. 322 (1939).
(8) Zeuthen, E. *C.R. Trav. Lab. Carlsberg, Ser. Ch* **24**, p. 479 (1943).
(9) Gregg, J. R. *Rev. Sci. Instrum.*, **18**, p. 514 (1947).
(10) Tolansky, S. *Multiple-beam Interferometry* (Oxf Clarendon Press, 1948); *Sci. Progr.*, **37**, p. 1 (1949
(11) Kuhn, H. *Rep. Progr. Phys.*, **14**, p. 64 (1951).
(12) Holden, J. *Proc. Phys. Soc.* [*London*] *B*, **62**, p. (1949).
(13) Bruce, C. F. *Nature* [*London*], **167**, p. 398 (19 *Austral. J. Sci. Res. A*, **4**, p. 117 (1951).
(14) Dyson, J. *Nature* [*London*], **167**, p. 397 (1951); *P Roy. Soc. A*, **216**, p. 493 (1953).
(15) *The Baker Interferometric Microscope* (London: Ba and Co. Ltd., 1954).
(16) Strong, J. *Modern Physical Laboratory Prac* (London: Blackie and Son Ltd., 1943).
(17) Brattgard, S., and Hallen, O. *Biochim. Biop Acta.*, **9**, 488 (1952).
(18) Lardy, H. A., Gibson, W. E., Hipple, J., and Bur R. H. *Analyt. Chem.*, **20**, p. 1100 (1948).

An instrument for the automatic recording of hysteresis loops

By D. C. GALL, M.I.E.E., F.Inst.P., H. Tinsley and Co. Ltd., London, S.E. 25, and J. D. WATSON, B.Sc.,
King's College, University of London

[*Paper first received* 12 *January, and in final form* 16 *March,* 1956]

The paper describes an apparatus designed to plot automatically the hysteresis loops of samples of ferromagnetic materials. The cycle of magnetization is carried out in about fifteen minutes. The induction in the specimen is measured by electro-mechanical integration of the induced electromotive force in a search coil, by a miniature electric motor having accurate proportionality between speed of rotation and applied voltage. The apparatus so far has been applied only to ring specimens in which the value of magnetizing force is directly dependent on the magnetizing current. The magnetizing force, in the case of the ring specimens used, is measured in terms of the voltage drop across a shunt carrying the magnetizing current. Novel features of the design are the method of integrating the search coil voltage, and the incorporation of automatic control of the magnetizing current, with the object of maintaining the search coil electromotive force within the range of the integrator motor at all times.

e plotting of hysteresis loops is normally carried out with aid of a ballistic galvanometer, working in steps from ration round half the loop. This procedure is assumed give the "static" loop, and has been shown to correspond sely to the loop obtained with alternating magnetization very low frequency. The aim of the automatic hysteresis-p plotter is to carry the material round a complete cycle ween given limits of induction, proceeding continuously as alternating-current magnetization, but at so low a speed t eddy-current effects are negligible.

number of such hysteresis-loop plotters have been igned. One of the major problems is the integration of search-coil voltage to give a measure of the magnetic flux he specimen. The search-coil voltage is normally only a microvolts persisting for a number of minutes, thus cluding the use of a simple resistance-capacitance integtor, due to the very large time-constant, and attenuation. st practical forms of integrators invoke the negative-lback amplifier principle, in which the output signal is erentiated and fed back to the input, under which condition amplifier behaves as an integrator. Several integrators of type have already been used in automatic hysteresis-loop orders. Cioffi(1) used a mutual inductance as differentiating uit, giving an amplifier output current proportional to the e integral of input voltage; Brockman and Steneck(2) d a capacitance-resistance circuit in the feedback loop. cently, a hysteresis-loop tracer was described by Ross(3) ng an amplifier with feedback from a tachometer generator, chanically coupled to the recorder movement.

Consideration of the previous instruments led to the clusion that there was a need for a somewhat simpler m of hysteresis-loop plotter, which would deal satisfactorily h rectangular-loop materials.

The instrument to be described integrates by means of a -inertia motor of special construction, which has a speed rotation closely proportional to applied voltage. This tor, which moves the recorder pen, is driven from a d.c. vanometer amplifier to which the input is the search-coil ctromotive force. The magnetic cycle is obtained by a tinuous variation of magnetizing current, this being plied from a long, helically wound, centre-tapped slide-e with a motor-driven contact. This applies a slowly rnating magnetizing force to the specimen, and, in order plot this on the recorder unit, the voltage developed across eries resistor in the magnetizing circuit is used to position chart cylinder with the aid of a follower mechanism. Thus *B* co-ordinate of the hysteresis loop is parallel to the axis rotation of the recorder drum, while the *H* co-ordinate is tangential, and is produced by drum rotation. A block diagram of the instrument is shown in Fig. 1.

The instrument traces hysteresis loops automatically at a rate determined by the maximum voltage which may be applied to the integrator motor. As the magnetizing force changes and reaches the steep sides of the hysteresis loop in the region of the coercive force, the search-coil electromotive force increases, and would overload the integrator, causing some of the loop to be lost. In the case of rectangular-loop materials the sudden change would be very large and, in order that the recorder may successfully be used with these materials, an additional controller is provided which limits the search-coil amplifier output to the maximum rated voltage of the integrator motor. This means that the motor-driven slide-wire contact must move at a speed depending on the part of the loop being traversed. Near saturation it moves fast, and slows down nearly to standstill as the sides of the loop are traced. (This control of the rate of change of *H* in order to maintain an approximately constant search coil voltage has not been achieved automatically in previous recorders, although a manual control was used in apparatus developed by Morris and Langford.(4))

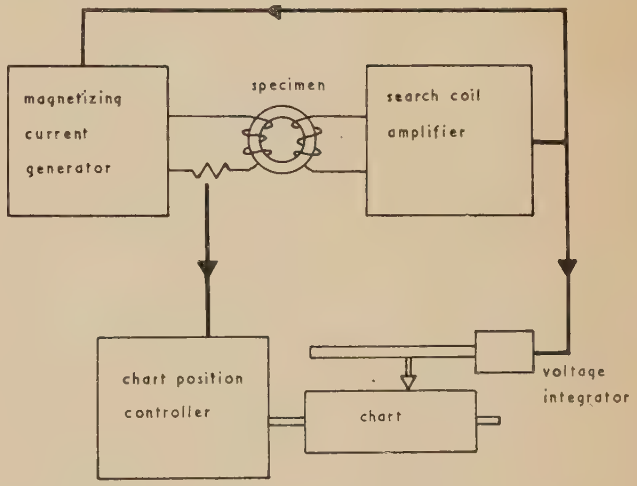


Fig. 1. Block diagram of automatic hysteresis-loop recorder. The search coil e.m.f. controls the rate of change of current

The instrument has been used successfully on rectangular-loop materials, and results are given of comparisons between loops obtained for the same specimen on the recorder, and using a ballistic galvanometer. Minor loops have also been traced on the main loop with much greater speed than would be possible with the "step-by-step" method.

DESCRIPTION OF THE INSTRUMENT

The galvanometer amplifier circuit used in the equipment has been previously described fully,⁽⁵⁾ and a brief account only is given here of the basic circuit.

The anode current of a thyratron, having its anode and grid excited in anti-phase, will commence to flow when the grid control ratio is exceeded. Thus the anode current can be varied by a change in phase of grid voltage. In the amplifier circuit, the thyratron grid is fed *via* a condenser-resistance phase shift circuit, the resistance being that of the vacuum photocell. As the photocell illumination is varied by galvanometer deflexion, the anode current changes. By the application of negative feedback from the output to the galvanometer circuit, the gain can be stabilized, and at the same time the apparent galvanometer period is reduced.

PLOTTING H

Referring to the circuit diagram in Fig. 2, the specimen is magnetized from a variable d.c. voltage source, obtained from the long slide-wire R_2, which consists of thirty turns of copper–nickel (Eureka) wire, wound as a helix on a 7 in. diameter insulated brass drum. The sliding conta attached to a radial arm which is rotated by a d.c. m Stops and reversing switches are provided at each extr of the wire in order to keep the contact in cyclic motio

The voltage developed across a series resistor ir magnetizing circuit is a measure of the magnetizing cu and, in the case of a ring specimen, the applied field. voltage is used to position the cylindrical chart by rot about its axis. The value of the series resistor and the tivity of a series milliameter are adjusted by the same r changing switch, so that full-scale chart deflexion ca obtained for currents of 50, 100, 200 and 400 mA. A var series resistor enables the maximum current reached t adjusted, so that the desired peak value for *H* can be obtai

The chart-follower mechanism consists of an error-se circuit using the galvanometer amplifier. The error sig obtained by comparing the voltage developed across the s resistor mentioned above with that existing at the sl contact of a potentiometer, the contact being rotated wit drum. The servo-amplifier and motor thus cause the to move to a position corresponding to the magnet current.

An electromagnetic damping element is added in the of velocity feedback. A metal disk, coupled to the s motor, rotates between the poles of a permanent magnet. the voltage developed across a radius is applied in oppos to the error signal. This satisfactorily eliminates huntin

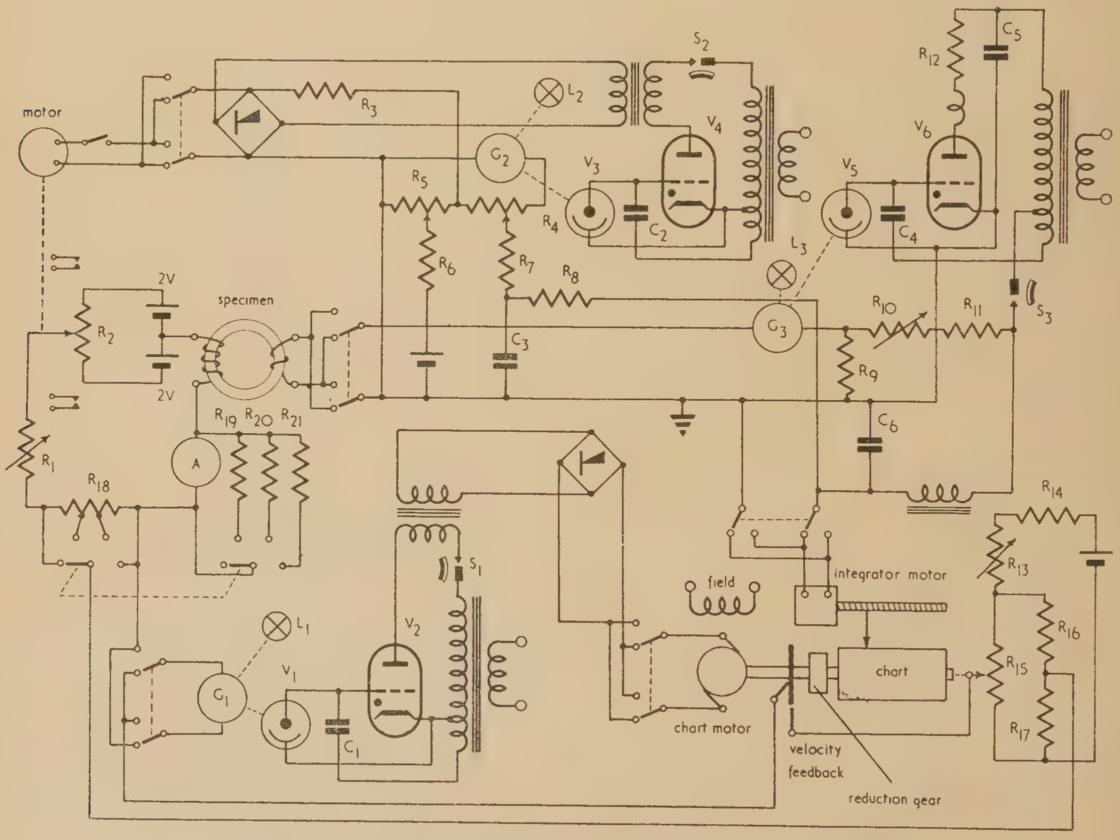


Fig. 2. Circuit diagram of automatic hysteresis-loop recorder

$R_1 = 100\ \Omega$
$R_2 = 2\ \Omega$
$R_3 = 3\ \text{M}\Omega$
$R_4, R_5 = 25\ \Omega$
$R_6 = 150\ \text{k}\Omega$
$R_7, R_8 = 1\ \text{M}\Omega$
$R_9 = 0{\cdot}1\ \Omega$
$R_{10} = 25\ \text{k}\Omega$

$R_{11} = 2\ \text{k}\Omega$
$R_{12} = 1\ \text{k}\Omega$
$R_{13} = 25\ \Omega$
$R_{14} = 20\ \Omega$
$R_{15}\text{–}R_{17} = 100\ \Omega$

$C_1 = 200\ \text{pF}$
$C_2 = 120\ \text{pF}$

$C_3 = 12\ \mu\text{F}$
$C_4 = 120\ \text{pF}$
$C_5 = 0{\cdot}1\ \mu\text{F}$
$C_6 = 2\ \mu\text{F}$

S = thermal delay

Photocells = VA26T
Thyratrons = GTIC

Galvanometers.
50 Ω. 50 mm/μA at 30 cm
Free period 2 s

Lamps, 12 V, 10 W

Integrator motor = Electro Methods,
type 902, 12 V

eversing switches, operating a relay circuit not shown in diagram, cause the motor-driven slide-wire contact to nge its direction of motion when the limit of travel is ched. It has been found possible to effect a simplification reversing the polarity of the error signal, and that of the o-motor input, simultaneously with a change of direction lide-wire contact motion. The servo-amplifier need now ond only to unidirectional input, but will not, however, rect for overshoot in this circuit. The rotational velocity the cylinder was considered to be low enough to reduce errors to negligible proportions. At its lowest speed, the rt cylinder would make approximately five discrete jumps move 1 mm, which was found quite suitable to give a oth curve.

particular use to which this instrument is being applied he examination of minor loops, which are readily plotted reversing the direction of tracing at any desired point of cycle, for the required amplitude of *B* or *H*. This control n the form of a push switch.

PLOTTING B

he search-coil amplifier is also of the galvanometer-otocell type previously mentioned. Negative feedback is lied to the circuit to linearize the gain, and to stabilize inst circuit and supply variations. The output, consisting half-wave voltage pulses, is smoothed and applied to the egrating motor *via* a reversing switch, which is necessary e an amplifier sensitive only to positive signals is used, the search-coil electromotive force changes sign at the of each half magnetizing cycle.

he integrator motor is a readily available type of precision struction, having an armature moment of inertia of 3 g cm^2. Rotation of the motor is arranged to displace pen parallel to the axis of the chart cylinder by means of ead screw and gear train. Thus the pen displacement is portional to the change in flux linkages with the search . The accuracy of the instrument depends on the linearity the speed-applied voltage characteristic of the integrating chanism, so a check was made by measuring the pen ocity for various applied voltages. The result is shown in . 3. Up to the full load voltage of 12 V, the experimental nts lie on a straight line within the limits of experimental or. Above this voltage the pen velocity does not increase fast as the applied voltage and the error reaches 2·5% for applied voltage of 14 V.

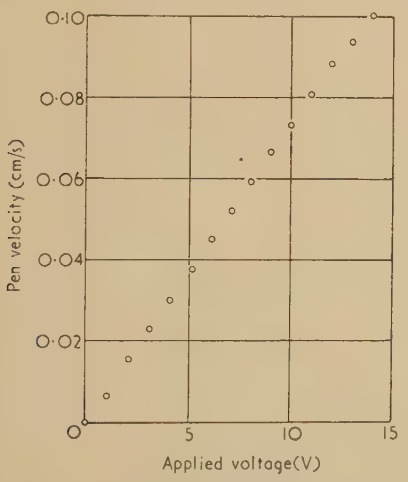


Fig. 3. Linearity test of integrator

MAGNETIZING-CURRENT CONTROLLER

The need to control the rate of change of magnetizing current arises from the sudden increase in search-coil electromotive force in the region of the coercive force, which would cause a part of the loop to be lost through an integrator motor overload. The ideal case of a constant search-coil electromotive force is not easy to attain, although this controller has been found satisfactory for rectangular loop materials.

A galvanometer-photocell unit with voltage feedback is again used, with a rectified output to drive the slide-wire motor. The amplifier input comprises two signals. The first, a d.c. voltage from a dry cell, determines the maximum output and hence the maximum rate of change of magnetizing current. The second input is derived from the search-coil electromotive force, and is applied in opposition to the first, causing the slide-wire motor to slow down as the search-coil electromotive force increases. The magnitudes of these signals can be set by adjustment of panel controls, which are pre-set to suit the specimen.

The instrument can be used without any special precautions to reduce mechanical disturbance, and no trouble has been caused in either amplifier or controllers by using chassis-mounting galvanometers. The search-coil amplifier uses a liquid-filled galvanometer, which renders this unit immune to severe shock, thus making the equipment suitable for factory conditions.

Since thermo-electromotive forces can cause drifts in a sensitive d.c. amplifier the input circuit of the search-coil amplifier is made entirely of copper.

CALIBRATION OF H AND B SCALES

The chart calibration of *H* depends on the potentiometer R_{15}, and the associated d.c. supply. Thus, since the current drain from the dry cell is small, the calibration will remain constant for several tests. The mean value of *H* in a ring specimen can be calculated from the mean path length and number of turns, whilst the amplitude of the chart movement can be made to give an easy-to-read scale by adjustment of R_{13}.

The calibration of *B* is in gauss units, but in order to allow wide variation in the search-coil turns and specimen cross-section, the amplifier gain control R_{10} is calibrated in line turns per centimetre pen movement. The calibration was obtained by applying a known input voltage of 1% accuracy to the search-coil amplifier, and measuring the rate of pen travel. As an example, 40 μV produced 5 cm movement in 125 s, giving $N\phi = et \times 10^8 = 1 \times 10^5$ line turns per cm of chart. The range of amplifier gain is such that flux linkage changes of from $0\cdot56 \times 10^5$ to 8×10^5 line turns can produce 1 cm pen travel. The somewhat lower sensitivity compared with delicate laboratory fluxmeters is more than offset by the advantages of automatic recording.

OPERATION OF THE RECORDER

An initial period of thirty minutes is allowed before use, in order to eliminate a small zero drift of the search-coil amplifier, which was thought to be due to the galvanometer suspension. The amplifier input is always short-circuited when not in use, and in this condition its zero can be set by rotation of the galvanometer case until pen drift ceases.

With the magnetizing winding terminals open-circuited, the recorder chart is set to mid-scale of *H*. Due to the switching circuits used, the contact on the magnetizing-current slide-wire is normally at rest at the limit of its travel, and, in this position, the peak magnetizing current can be adjusted when the specimen is connected by variation of a series resistor. A suitable scale is selected on the *H* range switch, and final chart displacement made by R_{13}.

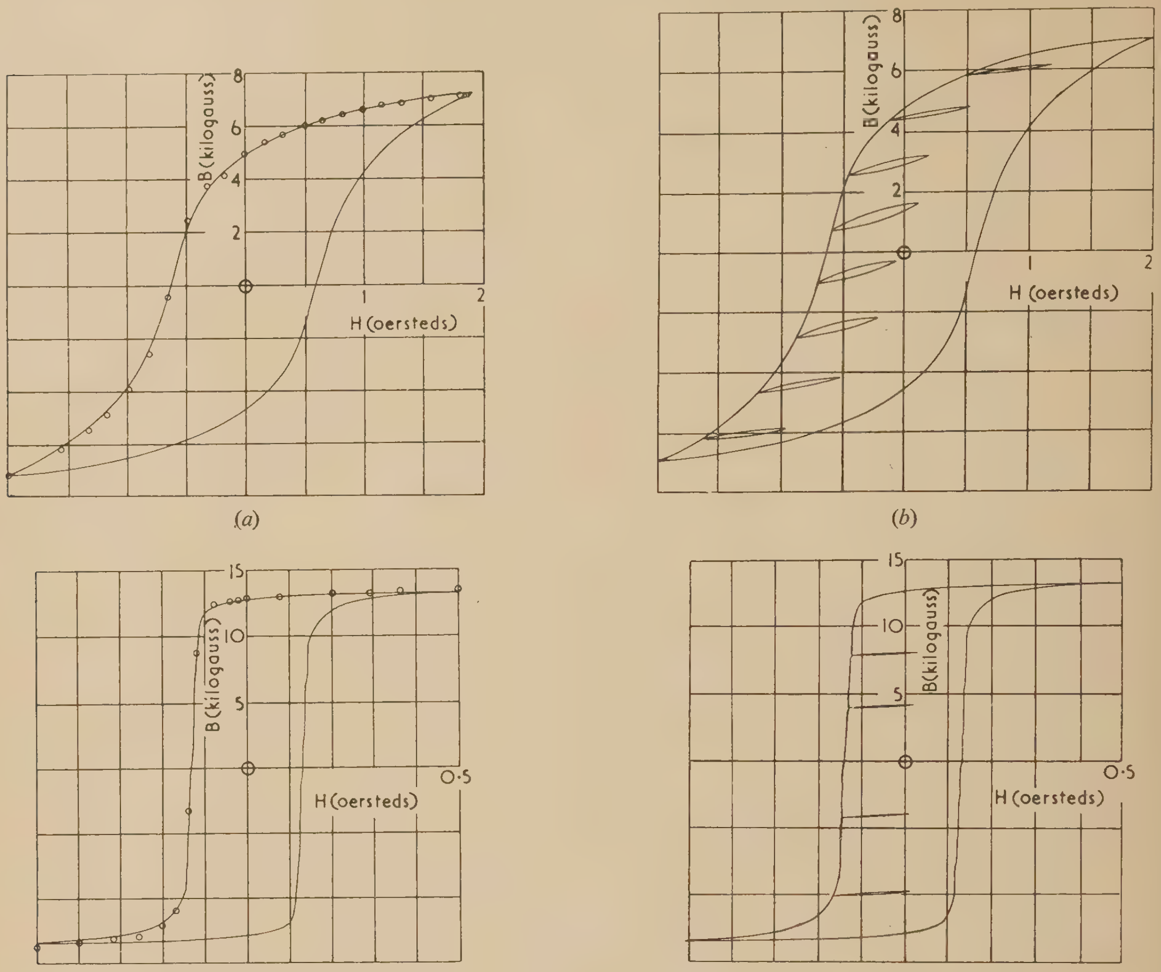
The search-coil is connected, and the amplifier gain control set to the calculated value. The pen carriage is placed in position and the slide-wire motor started. The two controls for the rate of change of magnetizing current are dependent on the magnetic characteristics of the material, and, with rectangular hysteresis loops, a low rate of change and greater control action are needed.

The instrument continues to trace loops automatically without attention, taking about fifteen minutes to complete a cycle.

TYPICAL RECORDED HYSTERESIS LOOPS

Hysteresis loops of 3·5% silicon iron ring stampings, and Telcon H.C.R. alloy spiral tape cores are shown in Fig. 4. Each core had a cross-section of approximately 1 cm², a mean length of 20 cm, and ratio of external to internal diameters of 1·2 : 1. Search coil and magnetizing windings were 100 turns each, uniformly wound. In the case of H.C.R., the specimen was enclosed in a suitable container to eliminate strain whilst being wound.

The points on the curves of Figs. 4(*a*) and (*c*) sho comparison with a fluxmeter test by the method of reve Minor loops of equal *H* amplitude are also shown in Figs and (*d*).



(*a*) (*b*)

(*c*) (*d*)

Fig. 4. Typical recorder loops, and comparison with fluxmeter

(*a*) and (*b*) Silicon iron. (*c*) and (*d*) Telcon H.C.R. alloy.

○ = points obtained in step-by-step method.

ACKNOWLEDGEMENTS

The instrument was developed by H. Tinsley and Co. L with the co-operation of King's College, London. authors wish to acknowledge the facilities provided by manufacturer, and to thank Mr. R. F. Spurr, who car out much of the work. Thanks are due to Prof. Greig initiating the project, and for helpful discussion during completion.

REFERENCES

(1) Cioffi, P. P. *Rev. Sci. Instrum.*, **21,** p. 624 (1950).
(2) Brockman, F. G., and Steneck, W. G. *Philips Rev.*, **16,** p. 79 (1954–55).
(3) Ross, H. McG. *Proc. Instn Elect. Engrs,* **101** p. 417 (1954).
(4) Morris, J. T., and Langford, T. H. *Proc. Phys. [London]*, **23,** p. 277 (1910–11).
(5) Gall, D. C. *Proc. Instn Elect. Engrs,* **89** (II), p. (1942).

The omegatron as a leak detector

By R. L. Bell, Ph.D., Services Electronics Research Laboratory, Baldock, Herts.

[*Paper received* 30 *January*, 1956]

The omegatron, a radio-frequency mass spectrometer, has been applied to the detection of very small leaks using the helium probe technique. Although intrinsically of similar sensitivity to the conventional magnetic sector mass spectrometer, its effective sensitivity can be very much increased by reducing the speed at which the leak and leak detector combination is pumped, an operation which is not feasible with the usual mass spectrometer. By this means leaks of 10^{-11} l. mb/s are readily found. The limiting sensitivity appears to lie in the 10^{-14} l. mb/s region.

A simple omegatron constructed for leak detection is described, and precautions to be taken in the use of helium mentioned.

number of devices for detecting leaks in vacuum systems ve been described.(1) The most sensitive of these, the mass ctrometer used with a helium probe, is reported to have a iting sensitivity around 10^{-9} l. mb/s (Ref. 1, p. 383). A k of this magnitude would limit the useful shelf life of a all vacuum tube to the order of days. A clear need exists a much more sensitive leak detector. The lower limit of erest is probably represented by leaks which would have a ticeable effect on the performance of a small receiving tube er a shelf life of say ten years, about 10^{-13} l. mb/s.

The conventional mass spectrometer is usually a demount-e device. In order to maintain the long molecular mean e path essential for its operation it is continuously pumped some tens of litres per second. To detect a leak of $^{-13}$ l. mb/s under these conditions implies the measurement a partial pressure of 10^{-14} to 10^{-15} mb—at present an possibility. The alternative approach is to slow down the ed at which the combination of leak and leak detector is ng pumped, bringing the pressure due to the leak within range of measurement, or to isolate it entirely from the mps, allowing the leak to accumulate in the isolated ume until the pressure rises to a measurable value. The ection of leaks by these means clearly requires that the ole leak detection system should lend itself to types of ocessing for vacuum normally employed on vacuum tubes mselves—namely, baking and bombardment outgassing of tal parts—and should, moreover, have a volume com-rable with or smaller than that of the tube having the leak. the omegatron is capable of fulfilling these requirements, becomes a natural choice as a detecting element for remely sensitive leak detection.

DESCRIPTION

General. The omegatron was developed by Sommer, omas and Hipple(2) for the accurate measurement of ton mass, among other things. It relies for separation of sses on cyclotron resonance of ions in a magnetic field.

Gas molecules present in the device are ionized by a fine ctron beam flowing in and parallel to a uniform magnetic d. An alternating electric field is applied at right angles he beam. If its frequency is close to the cyclotron reson-e frequency of an ion formed in the beam, the ion is racted and describes spirals of increasing diameter and rgy, finally striking a collector placed parallel to the ctron beam and some distance away. The ion current is portional to the partial pressure of the original neutral . (Since similar ionizing energies are used, the ionization babilities are not very different from those used in interpreting ion-gauge pressure measurements. Pressure values mentioned in this paper should be interpreted as equivalent ion-gauge nitrogen pressures.)

Design for leak detecting. Fig. 1 shows a simplified omegatron built for leak detection. The radio-frequency field is set up between two flat plates, 12 × 20 mm, having folded-in ends to improve the uniformity of the field. The interaction space is provided with end plates, having holes for the passage of the beam, which are operated 1 or 2 V positive to the radio-frequency plates in order to prevent ions escaping during the acceleration process. They also provide a field for sweeping out electrons formed in the ionization

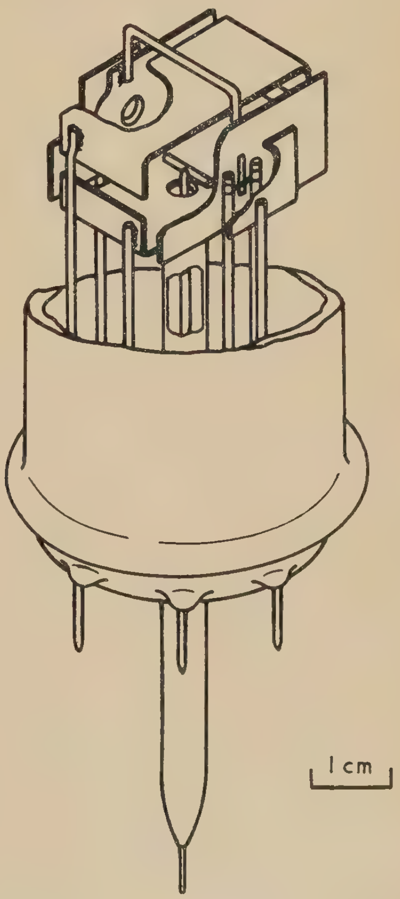


Fig. 1. Simplified omegatron built for leak detection

process, some of which otherwise find their way to the ion collector. This last is a strip of metal parallel to the axis and close to one radio-frequency plate mounted on a lead passing through a hole in the radio-frequency plate. The lead is surrounded by a coaxial screen tied to the plate and is finally brought out through a high-insulation pin. It is useful to maintain the ion collector slightly positive to the trapping electrodes, to ensure that only ions which have been accelerated by interaction with the radio-frequency field can reach it. It is also beneficial to apply a small negative potential to the upper radio-frequency plate to drain unused ions slowly from the interaction space.

The electron beam is generated by a 0·05 mm tungsten filament a few millimetres long, one trapping plate acting as the gun anode. The beam is defined by a 0·5 mm slit in the plate at right angles to the filament. Scattering of electrons throughout the device is prevented by a back plate behind the filament, at filament potential, and an electron collector outside the interaction space and positive to the trapping electrodes, both assisted in their action by the strong axial magnetic field. Beam currents of a few microamps at energies of about 70 V are used.

As will be seen from Fig. 1, electrodes are spaced from each other by gaps of the order of a millimetre, to give good access for gas to the beam.

None of the dimensions is critical; a usable omegatron can be built from basic materials in a few hours. If it is intended to use it as a more general mass spectrometer it is probably important to keep the radio-frequency field symmetrical about a plane through the beam and perpendicular to the radio-frequency plates, in order to avoid "mass harmonic" effects—i.e. acceleration of a mass *nM* when set to operate on mass *M*. It is also important in this respect to work well away from the critical background pressure discussed below.

In order to minimize possible spurious effects due to microphony in the first model, the electrode arrangement was mounted sturdily on glass insulators and the complete assembly then connected to the pinch. Subsequent models mounted directly from the pinch and about three inches away have not, however, shown signs of being affected by microphony.

Auxiliary equipment. The magnetic field can conveniently be obtained from a permanent magnet, between the poles of which slides the complete omegatron in its glass envelope. The pole pieces should be shaped so as to provide maximum uniformity of field in the interaction region. The magnet used has a minimum clearance between pole pieces of 1¼ in. and a pole piece diameter of 2½ in. It gives a field of about 2500 G at the centre, corresponding to a proton resonance frequency of 3·81 Mc/s. The restricted space between the pole pieces makes it necessary to economize in axial length of the omegatron, and in particular to shape the glass envelope so that there is minimum wastage of space. The necessity for a uniform magnetic field makes it essential to construct the omegatron with non-magnetic materials.

The radio-frequency signal can be obtained from a laboratory video signal generator; signals of the order of a volt are required.

A circuit diagram of the arrangements for obtaining the various potentials needed is shown in Fig. 2. Some complication is introduced by the fact that one side of the electrometer is usually earthed. The more critical potentials are continuously variable, to facilitate the initial setting-up of the gear. As this tends to be difficult, a description of a typical setting-up procedure is given in the Appendix. The omegatron is best battery-operated to eliminate mains-borne interference, and all supplies, leads and the omegatron i should be electrostatically screened, especially as the pu themselves may generate considerable interference.

It is useful, in order to reduce the effects of mois condensation, to put an earthing band around the g between the pin bringing out the ion collector and the of the omegatron. This absorbs any charge leaking fr other electrodes, held at very different potentials, wh would otherwise generate spurious signals across the h input resistance of the electrometer.

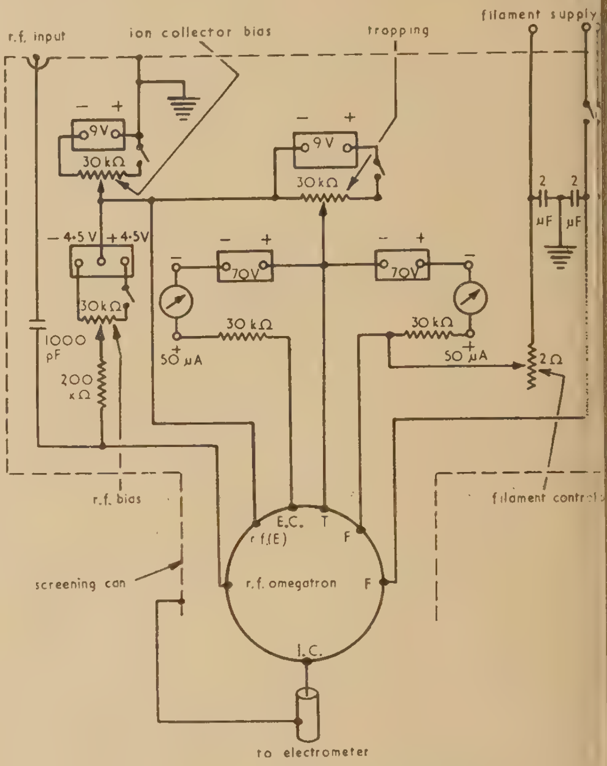


Fig. 2. Omegatron power supplies

VACUUM SYSTEM

Fig. 3 is a schematic drawing of the vacuum system. tube with the suspected leak is connected to the omegat and an ion gauge *via* a liquid air trap of small volume. Th are connected through a glass cut-off valve to a merc diffusion pump with two traps, backed by a mechan pump.

Baking a tube with an extremely fine leak may open close the leak. A case has been observed where the l disappeared entirely after a bake at 400° C. If the bak dispensed with, there remains a quantity of water vap and carbon dioxide to be removed, and this is expedited manipulating the cold traps.

The cut-off valve should be bakable and when clo present a conductance of less than 10^{-4} l./s.

The ion gauge is useful for checking that the total press is at a reasonable level for operation of the omegatron. difficulty is found in keeping the total pressure below 10^{-7} for several hours with the cut-off closed, if the omegatron, gauge, cut-off valve and trap are baked and outgassed bef sealing on the subject valve, and the liquid air traps are k ed. As this pressure is well below the critical background ssure for the omegatron, the accumulation period is in ctice limited only by the patience of the observer.

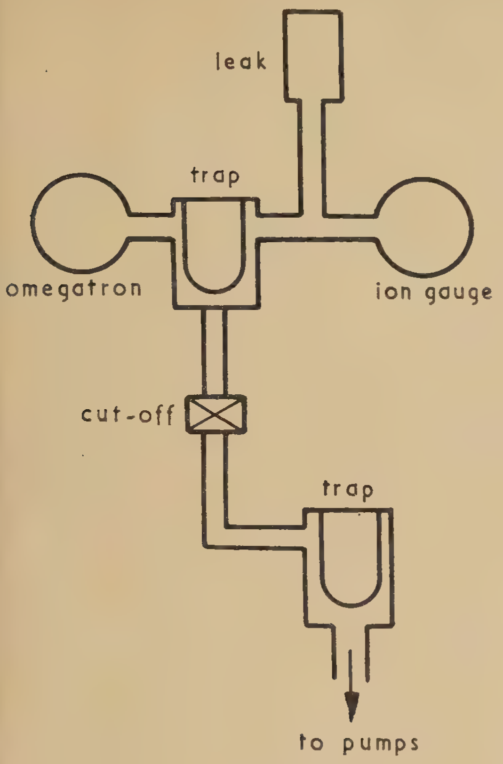


Fig. 3. Vacuum system

F, filament; T, trapping electrode; E.C., electron collector; .f.(E), earthing radio-frequency plate; r.f., upper radio-frequency plate; I.C., ion collector.

SENSITIVITY

Alpert(3) has shown, and experiments on the model scribed confirm, that the sensitivity of the omegatron as a essure gauge should be of the same order as that of the ual ion gauge, about 10 ions/electron millibar pressure. n currents of 10^{-14} A can be measured with a vibrating-ed electrometer. If the electron beam current is 10 μA, the nit of partial pressure which can be measured is thus $^{-10}$ mb. As the maximum background pressure at which s could be detected would be not much more than 10^{-6} mb e section below), the working gas—helium—must be esent in a concentration of not less than 10^{-4}. Alternatively maximum outgassing rate in a continuously pumped stem must not be more than 10^4 times the leak.

If the system is pumped at 10 l./s, the smallest detectable k will be 10^{-9} l. mb/s, which is of the same order as the nventional mass spectrometer. If the omegatron-leak mbination has a volume of 300 cm^3 and is cut off for an ur the leak giving a usable signal at the end of that time uld amount to 10^{-14} l. mb/s.

Notice that the zero shift of the electrometer need only be all compared with the signal during the few seconds quired to establish the presence or absence of a resonance tuning the frequency of the signal generator. With other ms of leak detector using accumulation, the zero must be ble over the entire accumulation period. It is this requirement which limits the sensitivity of the hydrogen gauge and the oxide-cathode oxygen leak detector.(1)

LIMITATIONS

The trajectory of an ion accelerated in the omegatron may consist of up to one hundred revolutions with a maximum diameter of a centimetre. The mean free path must therefore be appreciable compared with one metre; i.e. the total pressure in the device must not exceed some very small value. In practice, a background pressure of 10^{-5} mb will scatter the ions and suppress the desired signal, generating a number of spurious signals, some of which may be readily recognized as such, having non-integral mass numbers. Some deterioration in performance is noticed with a background of 10^{-6} mb.

Resolution of adjacent resonances with the omegatron becomes difficult at high mass numbers (in this case at about mass 30). In addition to this, when working under difficult conditions of background pressure and high sensitivity, resonances are apt to be distorted from their true position on the frequency scale. Both these effects tend to confine useful working gases in leak detection to those having small mass numbers.

A limit is set to the pressure sensitivity of the omegatron by the collection of stray current on the ion collector, which increases with the electron beam current. Measures taken to reduce the stray ion current, by introducing d.c. potential gradients in the interaction space, already contribute to distortion of the trajectories and loss of resolution at high mass numbers. However, there is practically no resolution problem with helium and it is possible that the pressure sensitivity could be increased by redesigning the omegatron with this object in mind. The detection of leaks would be speeded up by just that factor gained in sensitivity.

The X-ray pressure limit on the present design is likely to be low, of the order of 10^{-14} mb.

PERFORMANCE

The rate at which helium from the atmosphere seeps through the glassware of the omegatron and ion gauge was estimated from Ref. 3 to be about 10^{-14} l. mb/s. Thus the measurement of this rate of seepage constitutes a useful check on the maximum sensitivity. This can be done by cutting off the omegatron from the pump for half an hour. If at the end of this time the omegatron is switched on, it does, in fact, show a partial pressure of somewhat under 10^{-10} mb of helium, indicating a leak of the correct order of magnitude. The signal disappears after a few minutes owing to pumping of the helium by the omegatron. This is essentially Alpert's(3) experiment. Thus on the glass system described, atmospheric helium permeation is the real limit on sensitivity, at about 10^{-14} l. mb/s. Comparison of the omegatron with an ion gauge using hydrogen confirms approximately the pressure calibration used, and thus that a partial pressure of the estimated limiting magnitude, 10^{-10} mb, gives a readily distinguishable deflexion of the electrometer.

Large leaks, of the order of 10^{-9} l. mb/s, are obvious immediately when using the omegatron. Smaller leaks, 10^{-10} and 10^{-11} l. mb/s, have been found with it. Still smaller leaks have not yet been forthcoming for test.

Some trouble may be caused if the helium probe is allowed to play on glass parts for any length of time—large quantities of helium diffuse through the glass and in time build up a large apparent leak—10^{-10} l. mb/s in a typical case. Hence glass parts should be shielded from the helium and a fine jet used as a probe in preference to an enveloping hood containing helium. Helium is clearly of restricted use in finding leaks in glass valves. Fortunately (from this point of view) many of the leaks in the range of interest occur in metal systems.

CHOICE OF WORKING GAS

Because of its small mass, helium diffuses through leaks at a high rate and, once inside, gives a completely unambiguous indication on the spectrometer of the presence of a leak. On the other hand, its high cost and its ready permeation through glass parts make it worth considering other detecting fluids as alternatives for special applications.

Of the cheaper probing gases, hydrogen is usually to be found already present in the system, since most tube parts are fired in hydrogen; moreover, it is one of the dissociation products of water vapour, usually also present. Furthermore, hydrogen is rapidly pumped by hot ion gauge or omegatron filaments. Nitrogen and oxygen also tend to be already present, and in any case are already flowing into the leak if there is one. Also their masses are a little high for straightforward interpretation of the omegatron response.

Neon has been considered as a possibility for overcoming the helium contamination of glass. However, a small resonance due to neon (mass 20) could very easily disappear in the skirts of a large resonance due to water vapour (mass 18). In any case glass is to some extent permeable to all the rare gases.

It would seem that helium, used sparingly, is in general the best choice for detecting very small leaks. Hydrogen is usable on larger leaks.

CONCLUSIONS

The advantages of the omegatron described for detecting small leaks by an isolation technique are clear; it is a small device, thus minimizing the accumulation volume, and in construction lends itself to thorough outgassing by standard valve processing techniques, during which the only critical part, the magnet, can be removed.

Even without accumulation its sensitivity is similar to the magnetic sector spectrometer, the most sensitive leak detector heretofore available, and so would be preferable if only on the ground of cheapness and simplicity. It shares with that device the need for low background pressures (less than 10^{-5} to 10^{-6} mb) and a preference for helium as the probing gas. This can cause difficulties, since glassware is permeable to helium.

When used to the limit of its potentialities the omegatron is able to detect a leak of 10^{-14} l. mb/s, extending the range of leak detection by a factor of 10^5 and covering every leak of interest in small valves. This large advantage over the magnetic sector spectrometer is mostly acquired by the use of accumulation in an isolated volume. The omegatron stands apart from other devices using accumulation for the re
that zero stability is not required over the accumula
period, but only over the short time required to dete
resonance at a known position on the dial of a signal genera

The speed with which a leak could be found could proba
be increased by forfeiting some resolution, not needed
helium, in favour of increased pressure sensitivity.

ACKNOWLEDGEMENT

The author is indebted to the Admiralty for permissio
publish this paper.

REFERENCES

(1) Dushman, S. *Vacuum Technique*, Chapter 6, Sectio
(New York: J. Wiley and Sons, Inc., 1949].

(2) Sommer, H., Thomas, H. A., and Hipple, J. A. *P*
Rev., **82**, p. 697 (1951).

(3) Alpert, J. *J. Appl. Phys.*, **25**, p. 202 (1954).

APPENDIX

Initial setting up

Measure the magnetic field. Work out the proton resona
frequency [f_{prot} (Mc/s) $= 1 \cdot 525\ B$ (k G)].

The total pressure in the device should be between
and 10^{-6} mb. Centre it in the magnet with the field ax
Set all electrodes around the interaction space to the
potential (earth), the filament at about -70 V, the elect
collector at $+70$ V.

Increase the filament temperature until an electron be
of about 10 μA passes through to the collector. Maxim
this by adjusting the magnet.

Raise the voltage of the trapping electrodes until so
positive ion current (10^{-11} to 10^{-10} A) appears at the
collector (about $\frac{1}{2}$ V). Apply about 1 V (r.f.) to the rad
frequency plate at a frequency of about one third the prot
resonance frequency. Raise the bias of the ion collector
reduce the ion current to about 10^{-12} A. Sweep the sig
generator slowly through a frequency equal to half the prot
resonance frequency (the H_2^+ line). A response should
observed on ion current when the frequency corresponds
the H_2^+ line, nearly always present. If not, increase
trapping potential to 1 V, re-bias the ion collector to remo
most of the increase in background current, and try aga
increasing the radio-frequency voltage to 5 V if necessary.

Adjust trapping, radio-frequency plate and ion collec
bias and radio-frequency amplitude to give optimum sen
tivity and line width. Check that there are no spuric
responses at mass 3/2, 3, etc.

The spectrometer should then operate well on heliu
mass 4. Settings are different for high mass numbers. If
H_2^+ line can be found, introduce some water vapour a
pump down to 10^{-6} mb.

An apparatus for producing air of controlled relative humidity for hygrometer calibration and testing

By L. A. Cram, B.Sc.,* The Imperial Tobacco Co. (of Gt. Britain and Ireland), Ltd., Bristol 3

[*Paper first received* 9 *January, and in final form* 14 *March,* 1956]

Wet and dry air streams are mixed in variable proportions to produce air between 30 and 85% r.h. This humidity is stabilized by automatic control using an electrolytic hygrometer. Calibrations reproducible to better than 0·2% r.h. can be carried out quite quickly.

calibrate any device for measuring relative humidity there two essential requirements, Firstly air must be available a constant humidity which it must be possible to change. condly the humidity of the air must be determinable. This per describes a solution to the first requirement. The ond requirement was to be solved by the use of a funda-ntal hygrometer, such as the gravimetric hygrometer or dewpoint instrument, and is not dealt with here, although constant humidity system to be described was designed use with either of these instruments. The apparatus was de for calibrating electrolytic hygrometers to an accuracy 0·3% r.h. so an air humidity constant to 0·1% r.h. was aim. Such constancy has naturally required accurate trumentation but the method used is basically simple and apparatus is easy to operate.

CHOICE OF METHOD

Four main types of system can be used to produce air for ibrating hygrometers. One is basically static and the other ee—two temperature, two pressure and two air stream thods—are all dynamic.

Equilibrium with solutions

The method which uses air in equilibrium with saturated t solutions, or with unsaturated solutions of sulphuric acid glycerine, is still popular because of its simplicity; but the nplicity and speed are lost if accuracy is required. Further-re, for the calibration of electrolytic hygrometers, no risk y be taken of contamination by salt molecules or by phuric acid.

Two temperatures

Air may be saturated at one temperature and then heated the working temperature. Wexler(1) and Cutting and on(2) have used this method. Altering the humidity is w for it involves changing the temperature of the whole urator. To overcome this Wexler used a multiplicity of urators, each in its temperature bath, and an ingenious eumatic changeover switch. Even this additional com-xity does not give the versatility of method (4) below.

Two pressures

Air may be saturated at a high pressure and then expanded the working pressure. This method has been developed Wexler and Daniels(3) and seems very versatile but rather nbersome.

Two air streams

A dry air stream may be mixed with a wet air stream in ustable proportions. Walker,(4) Glückauf(5) and Wexler(6) have used the divided flow system. This was the method chosen here. It is a dynamic system applicable to a non-recirculating apparatus, as is required for use with a gravimetric hygrometer. It is simpler than the other dynamic methods in requiring only one temperature controlled bath and no pneumatic changeover switches or high-pressure systems. Furthermore, it is versatile and the humidity can be changed very quickly and simply in a continuous fashion by altering the mixing valves. This is important if many closely-spaced calibration points are required.

The novelty of the present system lies in the use of an electrolytic hygrometer element in an automatic control system for maintaining the air at constant humidity. This has resulted in a simple apparatus giving good consistency and yet having good versatility. Saturated air is not used in the system since condensation problems are to be avoided. The wet air stream need not be saturated since calibrations are only required from 30 to 85% r.h. Divided air-flow systems which do employ saturated air often use it to obtain the humidity stability of the calibrating air. Another way of providing humidity stability is to use a large hygroscopic load, but this slows down the rate at which intentional changes in humidity can be made. It is far preferable to use an automatic control system, as has been done here.

Controlling element. The success of such a system depends, of course, on the availability of a suitably rapid and stable humidity sensing element. The lithium chloride electrolytic resistance hygrometer described by Dunmore(7) appeared suitable for this purpose. These were not easily available in this country but a programme of work to study their design and manufacture had already been started (it was primarily for the testing of these that the calibration apparatus was required). Several novel and useful designs were made and one of these was particularly suitable for the calibration control requirement. It is of sturdy construction; is believed to show no drift of its resistance humidity characteristic with time; shows no hysteresis and is extremely rapid in response. (It will follow a small humidity change in about a second.) The name "humel" is used in this paper as a convenient contraction for these "electrolytic humidity elements."

APPARATUS

A diagram of the apparatus is given in Fig. 1. In its design every effort was made to produce stability of the flow rates and humidity without automatic control, so as to minimize the control range needed and thus improve the precision obtainable with the automatic control. All the air is first dried by passing it through a silica gel column. This ensures that the humidity of the wet air stream (which is not saturated) is independent of room humidity. The pump comes first in the system so that any leaks will be from the system and not into it. (Leaks must in any case be minimized to avoid loss of pressure.) Next to the drying tube is a glass wool chamber to prevent any silica gel dust from passing into the rest of the system where it might clog valves or form an unwanted hygroscopic load. The air next divides into two main channels and a subsidiary one for control purposes, with a needle valve and flow gauge fitted in each. One of the main channels leads to an atomizer A (made by Aerosol Ltd.) for humidification. A glass wool bottle removes the airborne droplets from this wet stream before it joins and mixes with the other main stream which is still dry. The atomizer and droplet-removing bottle are both submerged in the temperature-controlled water bath, but nevertheless the mixed air streams pass next through a special temperature equilibrating and flow-mixing pipe before entering the working chamber. Here the air passes first over the controlling humel C and then over the elements to be calibrated. The humidity control air path is normally closed by a magnetic valve. It is opened by the control humel acting through an on–off electronic relay when that humel finds the air too wet. This permits a little extra dry air to join the mixed air part way along the temperature equilibrating pipe. The time taken by this air to reach and influence the control humel is about five seconds.

---

* Now at E.M.I. Engineering Developments Ltd., Wells, nerset.

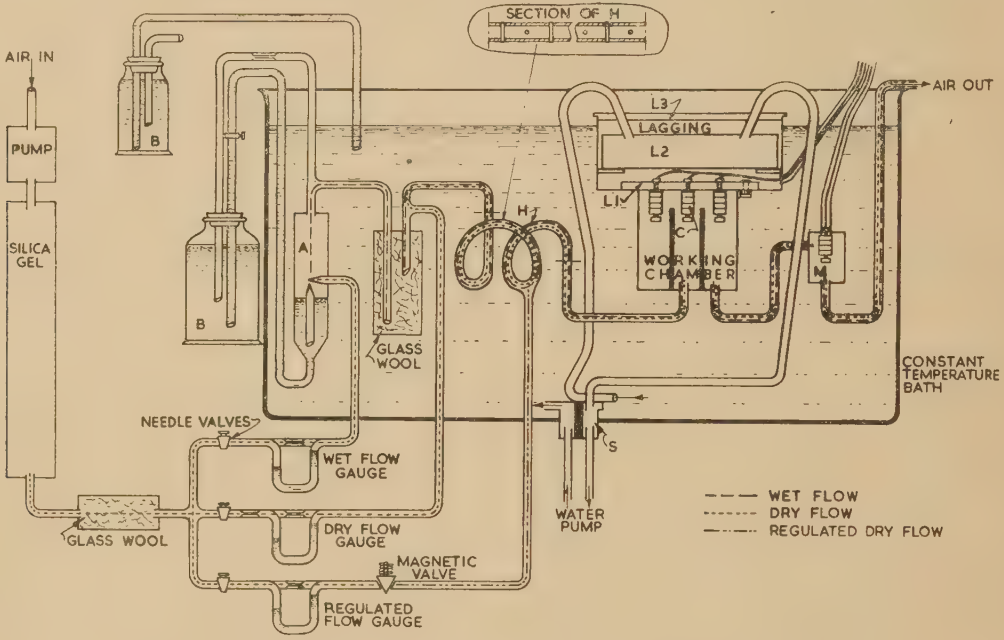


Fig. 1. Apparatus for producing air of controlled relative humidity

Finally, after the working chamber there is a tiny vessel M containing a humel which monitors the air on a recorder just before it leaves the water bath to enter the dewpoint apparatus or other humidity standard.

DETAILED DESCRIPTION OF PARTS OF THE APPARATUS

The calibrating chamber. Good temperature stability is required. A temperature change of only $\frac{1}{40}$° C will give an error in the relative humidity as determined by the dewpoint of 0·1% r.h. The calibrating chamber is made of copper but to facilitate removal and replacement of humels being tested it is not completely submerged in the water bath. It has three lids. The first, L_1, is of Perspex and carries sockets into which nine humels can be plugged. This lid is made airtight by a rubber gasket and is secured by eight bolts. The sec lid, L_2, is a water vessel through which water from the is passed *via* flexible rubber pipes attached at the "stra line" stirring nozzle S in the bath. Thus all the w circulated by the bath stirring pump passes through this Finally a Tufnol lid, L_3, covers all to minimize loss of from the water lid.

After screwing down the Perspex lid it has been fo necessary to pressurize the chamber to test for leaks, s even a tiny leak here adds a large hygroscopic load to chamber. Such a leak results in a fall or rise in tempera above the lid if the humidity in the chamber is lowere raised: and this temperature change is conveyed through Perspex lid to the humels. A thermocouple and a humel permanently fitted above the Perspex lid to monitor Their leads, together with those from thermocouples humels within the chamber, are taken out through copper tubes.

Temperature equilibrating pipes. The tubing used is $\frac{1}{4}$ inner diameter copper. For fast regulation by the controll humel, C, it is necessary for the temperature equalizing to be as short as is satisfactory. The length required origin was four feet. However, a shorter improved tube was m by silver-soldering wires across its diameter at $\frac{1}{2}$ in. spaci each wire being put perpendicular to the one before it. T system is about ten times more efficient at transferring h to the air, and is easy to make.

Temperature-controlled water bath. As shown in Fig most of the equipment is submerged in a water bath. model 427 eight-gallon bath (by Townson and Mercer L is used. In a room of fairly even temperature the tolu regulator has given long-term stability of better than $\frac{1}{10}$ so long as the bath is not accidentally bumped. The b windows have been lagged. A temperature recorder usin type F thermistor (by Standard Telephones and Cables L has indicated a temperature oscillation of about $\frac{20}{1000}$ caused by the switching of the temperature regulator. phase of this oscillation varies across the bath but its amplit l the mean temperature are fairly constant all over the bath ept near the heaters. It was decided not to attempt to uce this oscillation but to eliminate its effects by always ing temperature readings as the heater switched off. An dible indication of this instant was provided by a home-de operations recorder. The chart of this recorder was d to check that the cooling water for the bath had been wing at the correct rate to give equal on–off times of the h heater for about ten minutes before starting a reading. is was done to ensure a constant mean temperature of the th, for it was found that a change in on-to-off ratio from 6 to 1 : 2, caused by changing the flow rate of the cooling ter, would change the mean bath temperature by $\frac{15}{1000}$°C.

Water level regulation. A regulator with syphon, *B*, is d to maintain the water levels. The regulator for the pirator water level has a capillary in its air tube to attenuate pressure variations which occur in the aspirator when the gnetic valve operates. Otherwise the regulator, being a e-way device, tends to overfill the aspirator. When first itching the air pump on, the water syphon of this regulator s to be closed until air pressures have stabilized.

Humels (electrolytic humidity sensitive elements). The mels made in this laboratory differ in electrode form from se described by Dunmore[(7)] and are designed particularly achieve good mechanical stability and to decrease the short-cuiting effect of dust particles by using greater electrode aration. Low thermal capacity elements have been de but in many applications the temperature is constant d a sturdier form is used. This sturdy design consists of n. diameter palladium disks clamped between polished rspex washers of the same diameter and $\frac{1}{4}$ in. thick. ternate disks are electrically connected by the two clamping lts which terminate in plug pins. The conduction path is med on the cylindrical surface of the electrode system by ping in a solution of lithium chloride and polyvinylacetate a water and alcohol mixture as described by Dunmore. C. measuring techniques are used and a good capacitor is t in series with the humel to avoid the long-term drift which curs if there is a direct current of the order of 1 μA.

Control circuit. A simple control circuit has been devised corporating three diodes and a double triode and requiring stabilized voltage supplies. As may be seen in Fig. 2, . is used to supply a humel bridge, the output of which erates a Schmitt trigger.[(8)] A phase-sensitive a.c. version of the cathode-coupled trigger was at first devised and is now used in other circuits where the bridge contains no components having variable reactance (e.g. in thermistor bridges for temperature control). Though the humel impedance is primarily resistive it includes a capacitance which also varies with humidity. Consequently an a.c. bridge including a humel needs two variables to balance it. To avoid this complication without passing d.c. through the humel and polarizing it, the bridge was altered by inserting two diodes V_{1A} and V_{1B}. This bridge can now be balanced at any humidity with only one control and it gives an output suitable for a d.c. Schmitt trigger. The anode load of the second triode, V_{2B}, of the trigger contains a Post Office relay which will switch the magnetic valve. The common cathode load R_{13} of the trigger is variable and is used as a sensitivity control. When it is set to 100 mV sensitivity at V_{2A} grid it remains stable for months (equivalent to ±0·05% r.h. change at the humel). If, however, R_{13} is decreased slightly further, the circuit can be made to oscillate when the bridge circuit is near balance. This results in oscillation of the regulating valve of about a one second period but a drift of humidity in either direction causes an increase in either its open or shut period. This gives good proportional control and, furthermore, the audible clicking of the electromagnetic valve gives an indication of the constancy of conditions while a reading is being taken. The tapping on R_{14} is preset and is used initially to vary the value of grid signal on V_{2A} at which triggering occurs. In conjunction with R_1 and R_2 it determines the ends of the resistance range. Two ranges are provided by switch S_1.

To set to a new humidity, R_{15} is first reset as required and then the valves controlling the main dry and wet flows are adjusted until the magnetic valve ticks regularly. This takes about one minute but if precision is required it is usual to wait another five to ten minutes to ensure that temperature and moisture equilibrium have been re-established.

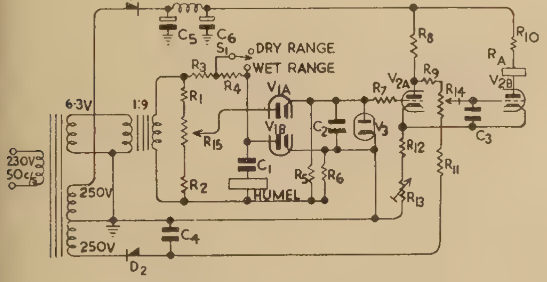


Fig. 2. Humidity control circuit

$R_1 = 25$ kΩ, $\frac{1}{2}$ W
$R_2 = 5$ kΩ, $\frac{1}{2}$ W
$R_3 = 100$ kΩ, $\frac{1}{2}$ W
$R_4 = 2$ MΩ, $\frac{1}{2}$ W
R_5, $R_6 = 10$ MΩ, 1 W
R_7, $R_8 = 100$ kΩ, 1 W
$R_9 = 500$ kΩ, $\frac{1}{2}$ W
$R_{10} = 15$ kΩ, 1 W
$R_{11} = 1$ MΩ, $\frac{1}{2}$ W
$R_{12} = 68$ Ω, $\frac{1}{2}$ W
$R_{13} = 50$ Ω, 1 W
$R_{14} = 250$ kΩ, 1 W
$R_{15} = 50$ kΩ, 2 W

C_1, $C_2 = 1$ μF, 350 V working
$C_3 = 0{\cdot}1$ μF, 350 V working
$C_4 = 0{\cdot}5$ μF, 500 V working
C_5, $C_6 = 8{\cdot}0$ μF

V_1 = EB34
V_2 = 6SL7
V_3 = EA50

R_A = P.O. 3000 relay, 10 kΩ

D_1, D_2 = metal rectifier (250 V, r.m.s., 60 mA.)

PERFORMANCE

The equipment has been in use since 1951 with only minor modifications and is found to be reliable, convenient and accurate. Besides the calibration of humels it has been used for testing other types of humidity sensitive device, such as the anodized aluminium capacitors as described by Jason[(9)] and single crystals of salt as described by Wylie.[(10)] The humidity can be changed very quickly and this not only helps in calibration work but permits measurements to be made of the speed of response of elements. The usual air flow is 10 l./min, sweeping out the working chamber in about 6 s. This chamber is 4 in. in diameter and 5 in. deep and will accommodate elements up to 1½ in. diameter and 5 in. long. Temperature is measured by three thermopiles (each consisting of three pairs of copper constantan junctions) using a potentiometer sensitive to 1 μV (i.e. $\frac{1}{120}$° C). The calibrations have been made against a dewpoint hygrometer which uses photoelectric dew detection and on which the temperature sensitivity is $\frac{1}{40}$° C. Out of these calibrations have been obtained fitted curves:

$$\log_{10} R = a + bh + ch^2$$

where R is the humel resistance at humidity h (%) and $35 < h < 85$, and where a, b, c are constants varying slightly from humel to humel. Representative values are: $a = 11{\cdot}00 \pm 0{\cdot}02$; $b = (-1{\cdot}41 \pm 0{\cdot}09) \times 10^{-1}$; $c = (7{\cdot}3 \pm 1{\cdot}1) \times 10^{-4}$. Statistical analysis of 200 calibrations shows that the standard deviation of a single point from the appropriate fitted curve is 0·17% r.h. As this is the size of error to be expected from errors in measuring air and dew-point temperatures it suggests that the humel is a very precise instrument, more precise than anything else that can be used to test it. It follows that, if used as a control instrument, a constant reading indicates a constant humidity within ±0·17%. This is satisfactory, as the design requirement was for calibration to better than ±0·3% r.h.

When a calibration is being performed the control circuit is set in the oscillating condition that gives proportional control. There is then no modulation of humidity detectable at the test humels (sensitivity about 0·05% r.h.) and constant humidity ±0·05% can be maintained for about twenty minutes. If this control is needed for more than twenty minutes an occasional adjustment to the air flow is required to keep the oscillation period of the control circuit constant. If, however, the apparatus must be left unattended (e.g. overnight) the control circuit is set less finely, so producing a measurable humidity modulation at the test humels and a fluctuation on the monitoring recorder of ±0·2% r.h.

During such long periods an indicated constant humidity can only be real if the humel is stable. Apart from the known constancy of calibration against other humidity measuring devices, the long-term stability can be inferred from tests on tobacco: Samples maintained in cabinets at constant relative humidity (as indicated by humel) have shown no significant changes in water content over periods of several months.

CONCLUSION

A method has been described which provides a precision and yet versatile method of producing a flo air of controlled humidity. The apparatus has been use the range 30 to 85% r.h. at temperatures from 10 to 4 and calibrations have been made consistent to better 0·2% r.h. There appears to be no reason why the rang operating conditions should not be extended, provided avoids very humid conditions which might cause damag the humel.

REFERENCES

(1) WEXLER, A. *J. Res. Nat. Bur. Stand.*, **45**, p. 357 (1
(2) CUTTING, C. L., and JASON, A. C. *J. Sci. Instrum.* p. 338 (1953).
(3) WEXLER, A., and DANIELS, R. D., JR. *J. Res. Nat. Stand.*, **48**, p. 269 (1952).
(4) WALKER, A. C. *Bell Lab. Record*, **7**, p. 169 (1933).
(5) GLÜCKAUF, E. *Proc. Phys. Soc.* [*London*], **59**, p. (1947).
(6) WEXLER, A. *J. Res. Nat. Bur. Stand.*, **40**, p. 479 (1
(7) DUNMORE, F. W. *J. Res. Nat. Bur. Stand.*, **23**, p. (1939).
(8) SCHMITT, O. H. *J. Sci. Instrum.*, **15**, p. 24 (1938).
(9) ANSBACHER, F., and JASON, A. C. *Nature* [*London*], p. 177 (1953).
(10) WYLIE, R. G. *Nature* [*London*], **175**, p. 118 (1955).

A high pressure methane ionization chamber

By F. J. M. FARLEY, M.A., Ph.D.,* Atomic Energy Research Establishment, Harwell, Berks

[*Paper received* 18 *January*, 1956]

An ionization chamber, 2 in. in diameter and 8 in. long, using quartz-Invar seals is described. Filled with fractionally distilled methane to a pressure of 40 atm and operated at 12 kV the chamber has an efficiency of 10% for counting 3 MeV neutrons and a collection time of the order of 1 μs. Detailed information on counting efficiencies and delay times is presented.

For counting fast neutrons in the presence of γ-rays an ionization chamber containing a hydrogenous gas still offers some advantages over the Hornyak type of scintillation detector.(1) Successful operation of methane-filled ionization chambers has been described by Beghian and Halban(2) at 35 atm, and by Frazer(3) at 7 atm. Wilson and others(4) describe various types of counter which they have used. The present design is based on the quartz-Invar seal technique of Aves(5) which gives great strength for internal pressures and is particularly suitable for operation at very high voltages.

CONSTRUCTION

Fig. 1 shows the counter which is designed for filling pressures up to 50 atm. Into the stainless steel body *A*, 2 in. inner diameter by ⅛ in. wall, is screwed the Invar plug *B*, on which the electrode assembly is mounted. The chamfered groove at the end of the thread is tinned on both sides before assembly, using concentrated phosphoric acid as flux, and the final seal is made by flowing soft solder into this groove.

The electrode assembly consists of the collecting electrode *C*, a small quartz insulator (cut to size and flame polish Gooch and Housego Ltd., Ilminster, Somerset), the g ring *D*, a large quartz insulator *Q* and the plug *B*. T parts are cemented together with Araldite type 1 the setting resin. The metal parts in contact with the quart of Invar, to ensure that the quartz disks do not crack the assembly is cooled to room temperature after sto The arrangement is suitable for withstanding a high int pressure, because the quartz disks and the Araldite are under compression when the chamber is filled. A jig is to locate the electrodes accurately during assembly stoving. The chamber is pumped and filled through copper tube *E*, which is fitted with the metal tap *F*.

ASSEMBLY AND FILLING

High purity and clean conditions are necessary in chamber for successful electron collection at high press Accordingly the components are thoroughly degreased b assembly by means of trichlorethylene and a final rinse Analar acetone. After this they are handled only with ru gloves. The quartz disks are heated for five minutes to a 600° C immediately before assembly to drive off abso er vapour. When the stoving of the Araldite is complete electrode assembly is immediately sealed into the outer ll and kept under rough vacuum to avoid any reabsorption water vapour by the quartz.

---

* Now at Auckland University College, New Zealand.

he chamber is outgassed for two to three days at 100° C emperature which will not seriously weaken the Araldite its), the ultimate pressures being about 6 × 10^{-5} mm of cury (hot) and 2 × 10^{-5} mm of mercury (cold). The e of outgassing is then of order 5 × 10^{-4} mm of mercury ssure in twenty-four hours. The chamber is filled to the ired pressure with very pure methane obtained by fractional illation.

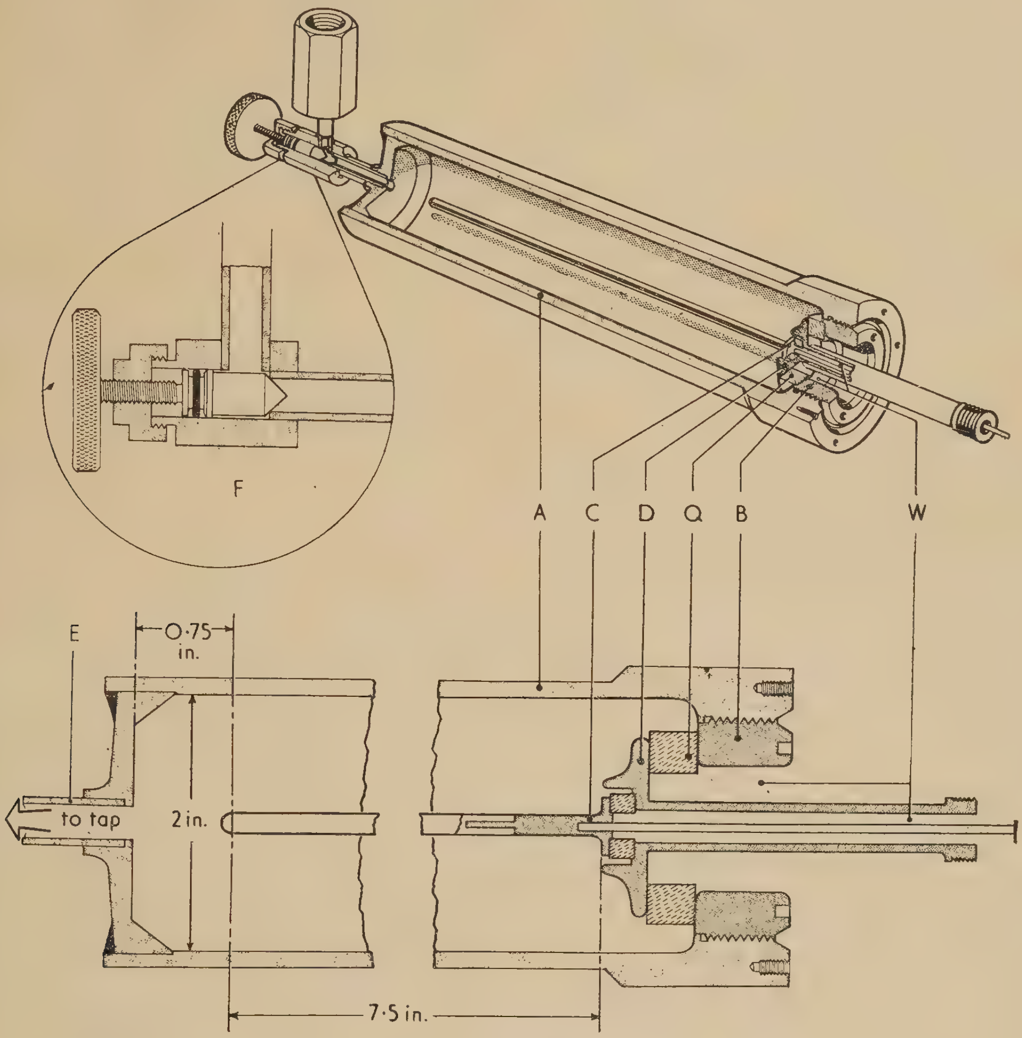


Fig. 1. Ionization chamber using quartz-Invar seals

n operation a positive high voltage, usually about 12 kV, pplied to the guard ring and collector electrode. To avoid rious pulses, due to corona discharge and surface leakage, esine wax is poured into the spaces *W*, (see Fig. 1), on the side of the quartz insulators. All high voltage points, uding the filter condensers, resistances and the coupling denser to the amplifier, are entirely embedded in wax.

PERFORMANCE

he chamber was operated in conjunction with a standard ar amplifier (type 1049B) and a high-frequency high tension power supply. Saturation curves for γ-ray and neutron excitation, taken five months after filling, are shown in Fig. 2. These curves were taken with amplifier integration time 8 μs to reduce the distortion of the curves by the varying rise time of the ionization chamber pulse, which, of course, depends on the high tension voltage. The differentiation time was 3 μs. The chamber was normally operated at 12 kV, with differentiation and integration times both 1·6 μs.

The efficiency of the counter as a function of discriminator bias is shown in Fig. 3. The pulse height scale was calibrated by injecting signals to the collector *via* a small condenser and is given in terms of equivalent electrons collected. The curves give the efficiency for various particles incident axially on the end of the counter. The measurements on monoergic neutrons were made using neutrons from the $H^3(p, n)He^3$ reaction by comparison with a standard long boron counter. Known sources of polonium–beryllium, ^{60}Co and spontaneous fission were used for the other curves.

The results show good discrimination against γ-rays at a bias of three to four scale units, and at these settings satisfactory counting of neutrons above 1·5–2 MeV is obtained. Higher energy γ-rays give somewhat larger pulses, but it has been found that a bias of four scale units cuts these out satisfactorily for most experiments. It should be noted that, for the fission neutrons, part of the rise in efficiency at low bias must be attributed to γ-rays from the spontaneous fission source. The results suggest that for counting neutrons under 2 MeV a lower pressure (say 20 atm) would be better. This would reduce the size of the γ-ray pulses, allowing operation at a lower bias which would more than off-set the reduced rate of primary neutron interactions in the gas. For higher energy neutrons, however, the present pressure (40 atm) is satisfactory, and could even be increased for certain experiments.

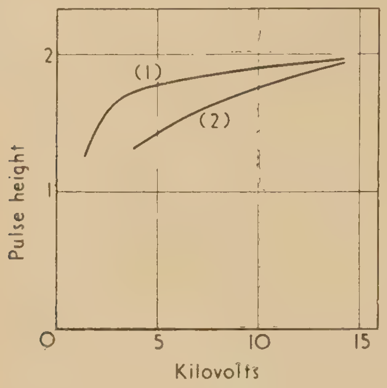


Fig. 2. Saturation curves for (1) γ-ray and (2) neutron pulses

Because of the high pressure filling there is an appreciable delay between the primary neutron proton collision and the arrival of the electrons at the collecting electrode. This varies with the position of the recoil proton track in the chamber. A further delay is introduced by the rise time of the amp (integration time constant 1·6 μs), and this again is vari depending on the pulse height and the discriminator The overall distribution of delays in normal operation measured by studying the neutron–γ-ray coincidences d a polonium–beryllium source, which gives 4·43 MeV γ from the first excited state of ^{12}C in coincidence with of the neutrons. The γ-ray signals (from a scintill counter), were artificially delayed, and the coincidence studied as a function of delay time with a resolving tim 0·1 μs. The results, displayed in Fig. 4, give directly distribution of delays in the neutron counting system. delays range from 0·2 to 1·9 μs with the most probable at 0·8 μs. Theoretically, Snyder's formula(2) gives a colle time of 1·0 μs maximum. The amplifier alone, however, differentiation and integration time constants 1·6 μs, w give a delay of 1·6 μs to the maximum of a pulse. F

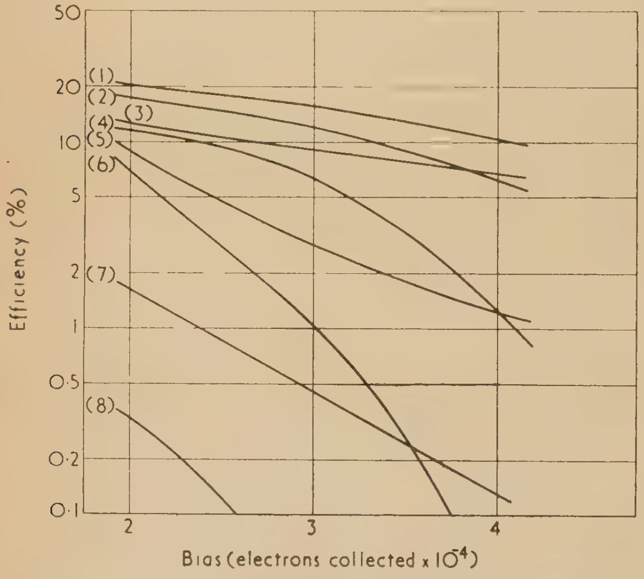


Fig. 3. Efficiency of counter used end on *versus* discriminator bias for neutrons of various energies and for γ-rays

(1) 3 MeV neutrons, (2) 2·5 MeV neutrons, (3) Po–Be neutrons, (4) 2 MeV neutrons, (5) fission neutrons, (6) ^{60}Co γ-rays (× 10), (7) background (counts/s), (8) 1 MeV neutrons.

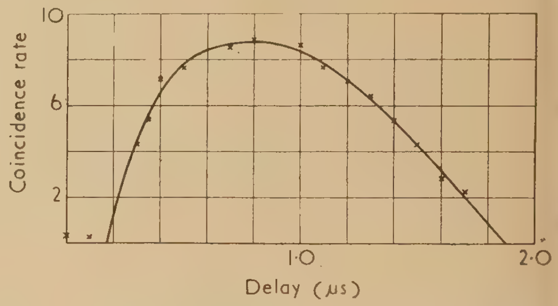


Fig. 4. Distribution of delays in neutron counter

therefore, appears to be in accord with theory, the high delays being attributed to the rise time of the amp for those small pulses which only just reach the discrimin threshold. The results show that this counter can be in coincidence and timing experiments, except when a short resolving time is required.

The counter has been in operation for six months, an sign of deterioration due to outgassing of the walls has observed.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. J. W. Hill for filling chamber with pure methane, and Mr. G. N. Harding, D. W. Colvin and Dr. W. D. Allen for their assistance advice. The method of measuring delay times was sugge by Mr. G. N. Harding. This work was done while author was on leave from Auckland University College, Zealand.

REFERENCES

(1) Hornyak, W. F. *Rev. Sci. Instrum.*, **23**, p. 264 (1952

(2) Beghian, L. E., and Halban, H. H. *Proc. Phys. [London] A*, **62**, p. 395 (1949).

(3) Frazer, J. S. *Phys. Rev.*, **88**, p. 536 (1952).

(4) Wilson, R., Beghian, L., Collie, C. H., Halban, and Bishop, G. R. *Rev. Sci. Instrum.*, **23**, p. 264 (19

(5) Aves, R., Batchelor, R., and Skyrme, T. H. R. *Sci. Instrum.* To be published.

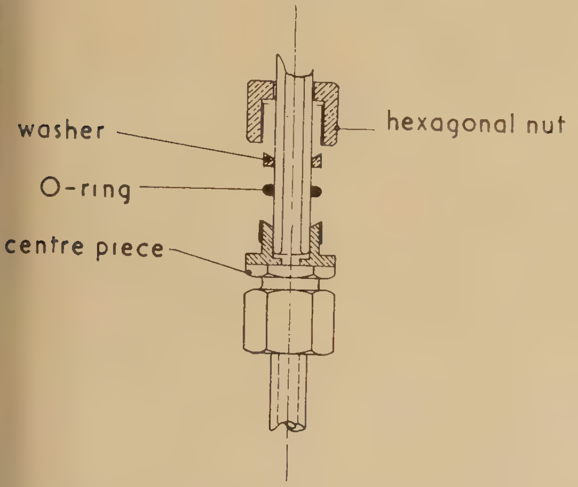
Laboratory and workshop notes

daptation of a gas and water union to high vacuum circuits

y A. D. Cassell* and D. A. Hockly, Graduate I.E.E.,
Electronic Tubes Ltd., High Wycombe, Bucks.

[*Note received* 12 *September*, 1955]

ndard gas and water unions (by Simplifix Couplings Ltd.) n be modified as demountable high vacuum unions for th metal and metal/glass circuits. The copper sealing rule in the union is replaced by an O-ring of suitable e, and the 45° faced washer reversed. The glass or metal es for union are selected to fit the Simplifix union and er insertion the hexagonal nut is screwed up finger-tight e figure). The ⅜ in. union adapted for use as a 10 mm cuum union uses a type V.O.R. 4A O-ring. Where mercury ffusion pumps are used it is advisable to plate the inside of e centre piece with a metal more resistant to mercury tack than brass.



Gas and water union modified for use as a vacuum union

These unions have been used in the standard double-ended rm to replace glass graded seals and wax joints or, with the read turned off one end, as a soldered connexion to metal stem. They appear to be satisfactory at pressures as low 10^{-6} mm of mercury.

---

* Now at Hanovia Lamps Ltd., Slough.

A parallel-spring cross-movement for an optical bench

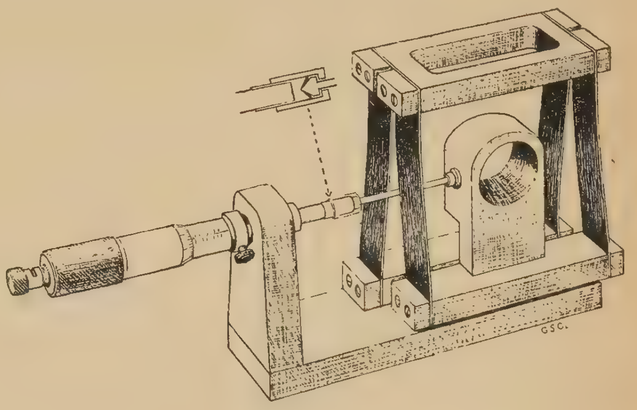
By Prof. R. V. Jones, C.B., C.B.E., F.Inst.P., Natural
Philosophy Department, University of Aberdeen

[*Note received* 10 *October*, 1955]

he cross-movement shown in the figure enables a component ch as an eyepiece to be translated over distances up to 5 mm, and its position to be measured to within a few icrons. Such a requirement arises, for example, in interrence, diffraction or magnification measurements; it is well tisfied by parallel-springs and it provides an opportunity r introducing students to these movements.

Approximately rectilinear displacement is achieved by two utually-compensating parallel-spring elements mounted de by side. This arrangement is less usual than those preously described,(1) but is more compact; it also makes the ading micrometer axis collinear with the track of the wire oss in the eyepiece, which is its correct location for accurate measurement. The placing of the drive symmetrically between the springs produces zero rotation of the eyepiece about a vertical axis, and the position of the drive half-way up the springs eliminates parasitic rotation about the eyepiece axis.(2) The two prospective defects of the design are a departure from rectilinearity due to the platform and eyepiece weights,(2) and a parasitic rotation about the direction of traverse, for which this particular arrangement of springs is not self-compensating. These defects will be shown to be of unimportant magnitudes.

The platforms and base are made of mild steel, normalized, and the springs are of hard beryllium-copper. The base, to which a pillar (not shown) is attached for fixing to an optical bench saddle, has dimensions 140 × 45 × 12·5 mm. A block of dimensions 80 × 20 × 10 mm is bolted to the base, and carries the springs of one component of the movement. These springs, and those of the second component, are 500 μ thick and 20 mm wide; their free lengths are 80 mm. The intermediate block has outside dimensions 80 × 45 × 9 mm, and the central rectangle of plan size 60 × 25 mm is milled away to save weight. The final block carrying the eyepiece has dimensions identical with those of the first block, except that it is 1 mm shallower, to avoid fouling the base when it moves. The clamping pieces are 6 mm thick, and are held to the blocks by 4 B.A. steel screws.



Parallel-spring cross-movement for an optical bench

The departure from rectilinearity is very small at 15 mm displacement, but amounts to a drop of 70 μ at 20 mm displacement. This is unimportant for most purposes. If applications arise where the drop would have to be smaller, one improvement would be to stretch a coil spring between the micrometer pillar and the eyepiece, of sufficient strength to pull the eyepiece carriage about 13 mm towards the pillar. The mid-position of the 25 mm traverse could thus be made to occur when the vertical springs were unstrained; the weights of the platforms and eyepiece would then move out to a maximum of ±12·5 mm from the unstrained position, which produces a negligible drop in the eyepiece platform. An alternative remedy is to redesign the movement so that the springs lie with their lengths horizontal instead of vertical, but the movement would then take up more length along the bench.

The performance of the design as regards parallelism of motion over 20 mm displacement is:

maximum rotation about vertical axis (yaw)	0″,
maximum rotation about eyepiece axis (pitch)	10″,
maximum rotation about direction of motion (roll)	60″.

These errors build up smoothly from zero to maximum with displacement. The roll is the only error of appreciable magnitude, but it produces no effect in the direction of measurement.

Improvements in the foregoing errors could be effected by the use of corrector clamps,(3) but these are unnecessary in the present application, where errors in optical benches are usually larger than those peculiar to the movement. The assembly was mounted, for example, on the 14 mm diameter pillar of a commercial bench, and it was found that the top of the pillar was bending by at least 10″ merely on account of the shifting of the weight of the eyepiece and its carrier. This was as large as the corresponding error in the spring movement, and would have been common to any design of movement, whether spring, kinematic or otherwise.

The base tends to bend concavely downward under the forces between micrometer and springs, but the thickness given is sufficient to restrict the effect so that the micrometer pillar does not move more than a very few microns. The error thereby introduced does not exceed that inherent in the micrometer.

A small but useful feature of the design is the retained wobble-pin. This is caged to the micrometer by a cap (of Perspex or metal) so that, while it is free for small displacements, it remains in such a position that when the eyepiece platform is drawn away from the micrometer, the free end of the pin is always ready to re-engage the female cone on the platform. This feature will be found to be of much convenience in spring movements generally.

REFERENCES

(1) Geary, P. J. *Flexure Devices*, B.S.I.R.A. Research Report M.18 (1954).
(2) Jones, R. V., and Young, I. R. *J. Sci. Instrum.* To be published.
(3) Jones, R. V. *J. Sci. Instrum.*, **28**, p. 38, 1951.

The use of a ball-point recording system on the Dines anemometer

By E. A. Cohen, Division of Meteorological Physics, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia

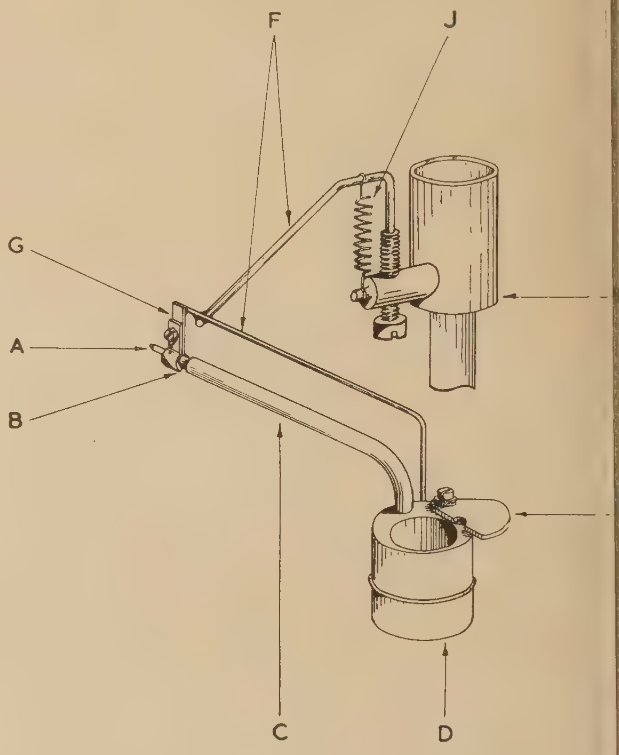
[*Note received* 13 *September*, 1955]

In most cases of ink recording, ink has to flow through fine ducts with the result that unattended recorders suffer from clogged pens. It is also difficult to achieve reasonably fine traces of constant width at varying pen-speeds. These problems are particularly troublesome in high-speed recording and also under hot dry conditions and with dusty atmospheres. A ball-point system which was designed for use on a Dines anemograph is described below, but similar arrangements are likely to be found useful in other applications.

The system produces a fine trace which is uniform in thickness over a large range of pen-speeds and is capable of functioning unattended for a few months. The ball-point of the system is filled once only and ink is poured into the reservoir as required. (The reservoir used requires "topping up" about once every two weeks.) The ball-point and reservoir may be changed within three minutes. The system is well protected against dust and evaporation. Diurnal variations in temperature and humidity have negligible effect upon its performance, and seasonal variations can be allowed for by simply adjusting the level of the reservoir.

The type of ball-point used consists of a sapphire s approximately 1 mm diameter which is housed in a plat socket 4 mm long. These are commercially available, sold as part of a replacement for Rubidor 54 pens m factured by Sphinx-Werk, Georg Linz and Co., Nurn Germany. In these pens, designed for use with ord writing ink, the feed is maintained by (*a*) rotation of the and (*b*) capillarity. In the design discussed here, (*a*) n for uniformity of trace width at various writing speeds (*b*) is controlled to adjust the width of the trace. This co is achieved by adjusting the relative levels of reservoir ball-point. In summer, employing the standard glycerine recorder ink, a negative head of 1 cm was found suit but in winter this had to be increased to about 2 cm. sumably this is because the relative speed of drying of i more important than the change in its viscosity.

The design of pen-housing and reservoir is shown in figure. The sapphire ball and its platinum socket *A* are



Ball point nib with mounting and ink reservoir

as purchased. A brass adaptor $\frac{1}{4}$ in. long *B* is made to s tightly over the socket. The outside diameter of this adap is made such that one end of a clear, flexible, plastic tub slides over it and makes an air-tight joint. The other end the tube slides into a hole in the wall of the reservoir *D* is cemented to it by lacquer. The reservoir and its cove are of clear plastic and are supported by an arrangemen brass wires *F* and copper strip *G* carried by the float roc of the Dines recorder.

To fill the system with ink, the unit which comprises ball-point and adaptor is filled first, using a capillary tube hypodermic syringe and needle. The reservoir is next fil and tilted to allow ink to fill the plastic tube then, while ink flows from the open end of the tube, the latter is slid o the adaptor for about $\frac{1}{8}$ in., leaving another $\frac{1}{8}$ in. of the adap to be gripped by the copper strip. During filling, care e taken not to allow air-bubbles to be trapped within the em. Cleanliness of ink is also an important factor in the formance and life of the ball-point.

pring *J* functions both as a tensile and a torsion spring. first property keeps the free end of the pen-arm firmly sed in its socket as the arm is swivelled when chart-nging. The second property, which is obtained by winding the spring by one or so turns before anchoring ends, provides a thrust of the pen-arm in the direction of chart, thus forcing the pen against the chart. In the sent application a load of 6 g wt. introduces a frictional ce of about 1·3 g. This force causes some interference h the free working of the Dines anemometer in light winds s than about 1 m/s), but does not appreciably affect it higher speeds. Unlike the pens supplied by the manu-turers of the anemometer, the ball-point pens used on the direction arms require about $\frac{1}{8}$ in. off-set between them.

he life of a ball-point ends when the ball wears sufficient its" on its surface to impede its free rotation in its socket, when solid bodies are wedged between ball and socket. continuous reversal of direction of rotation of the ball uces these factors. After six months' continuous use on speed arm of the anemometer, one ball-point produced ces which compared well with those produced by the illarity pens supplied by the manufacturers of the trument.

arly experiments leading to the present design were ssible due to the skill and co-operation of Mr. G. J. nderheiden.

A light interrupter of continuously variable on-off ratio

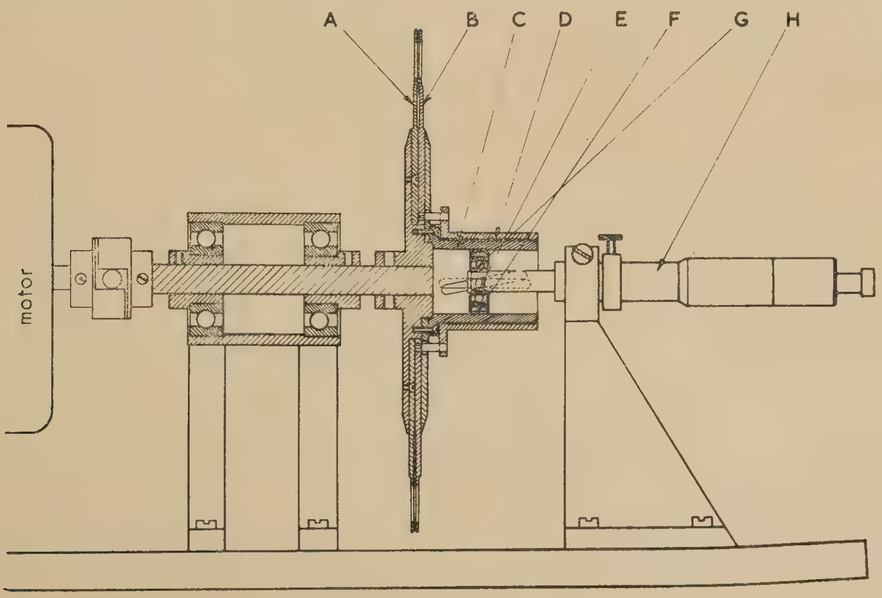
By T. P. Brody, B.Sc., Ph.D., British Dielectric Research
Ltd., Wood Lane, London, W.12

[*Note received* 29 *September*, 1955]

mechanical interrupter, with an on-off ratio variable tween 1 and 0 while in motion, has been developed for tical studies on semi-conductors. As it is essentially a light ensity attenuator capable of accurate adjustment, and is of a simple construction, it may be found useful in other fields of optical measurement. It can of course also be used as an optical square wave generator.

As shown in the figure, the device consists of two concentric disks provided with slots and rotatable with respect to each other. Disk *A* is fixed to the motor shaft, and carries with it sleeve *C* which has two helical slots milled in it. Disk *B* carries sleeve *D*, the latter having two axial slots of the same width as those on *C*. Sleeves *C* and *D* are interconnected by means of pins *E*, which are fixed into collar *F*, carried by a ball-bearing *G* mounted on the spindle of the micrometer head *H*. Adjustment is then made by turning the micrometer: this moves the pins *E* along the slots in the two sleeves, rotating *D* and its associated disk *B* with respect to *A*. With a normal 1 in. micrometer head, graduated in 0·001 in., an adjustment better than 1 : 1000 of the on-off ratio is easily obtained.

I wish to thank Mr. S. H. Cook for constructing the device and for suggesting some improvements.



Section through interrupter

A dual-purpose specimen spinner for transmission and reflexion X-ray diffraction

By P. N. Bestelink, and D. R. Holmes, M.A., D.Phil.,
A. Inst. P., Imperial Chemical Industries Ltd., Plastics
Division, Welwyn Garden City, Herts

[*Note received* 25 *October*, 1955]

Specimens for X-ray diffraction examination on counter diffractometers are often prepared in the form of compacted or pressed slabs, or rolled sheets. Samples prepared in this way frequently contain non-random aggregates and may possess other deficiencies, such as preferred orientation or over-large particle size. To minimize the effects of these deficiencies it is common practice to spin the specimen in its own plane; there are commercially available instruments for doing this when the Bragg–Brentano reflexion technique is being used.

In this laboratory it has been found advantageous to use both reflexion and transmission techniques for the polymeric materials being studied. A device for this purpose has been designed for use on a Hilger and Watts monitoring diffractometer, and has a base similar to that of the stationary and spinning specimen attachments available with this instrument. Figs. 1 and 2 show that the principal feature of the spinner is the hollow spindle *A* with a bore of 1 cm. This spindle carries at one end a worm-wheel *B*, and is rotated in ball-races *C*, at 60 rev/min by a worm *D*, on the shaft of the motor *E*. The bearing housing is clamped by a yoke *F*, forming part of a brass block *G*, which is clamped on a circular spindle *H*, from the base by means of an Allan screw. The other end of the hollow spindle carries a circular recessed flange *K*, in which glass or Perspex specimen holders *N* may be placed in a special washer *L* and secured tightly with the knurled cap-nut *M*. The plane of the specimen is adjustable both in translation and rotation about a vertical axis, a feature which makes for convenience in the initial alinement of the front surface of the specimen on the diffractometer axis.

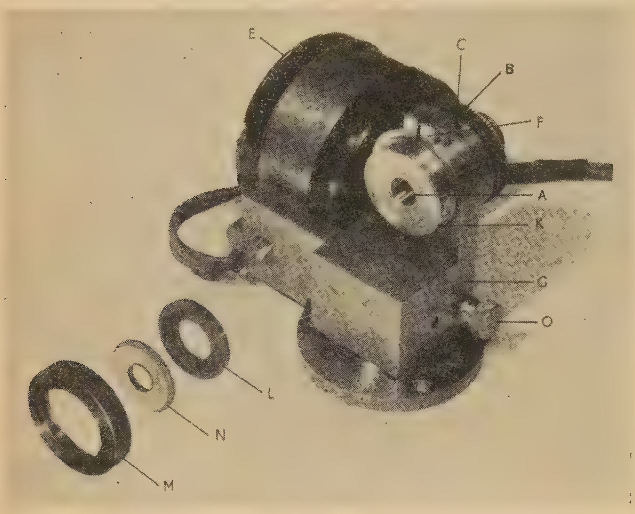


Fig. 1. Dual-purpose specimen spinner

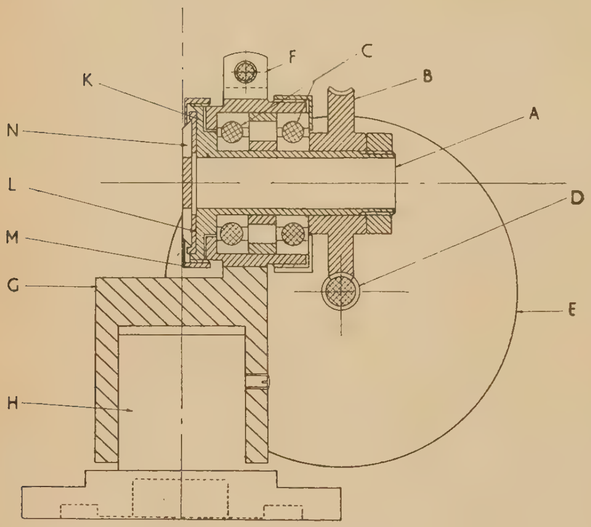


Fig. 2. Elevation of spinner (two thirds actual size)

For the Bragg–Brentano reflexion technique the device is mounted with the specimen plane parallel to the direct beam and the usual 2 : 1 drive of the counter and speci used. For the transmission technique the specimen sp is uncoupled from the counter drive and the spin clamped stationary with the specimen surface perpend to the direct beam by means of a clamping bar fro bolt *O* to the body of the diffractometer. The incident now enters through the hollow spindle and strikes the face of the specimen. The emergent diffracted beams an unobstructed path up to 2θ angles approaching The only other adjustment required to change from refl to transmission is the replacement of the washer *L* b with an increase in thickness equal to one-half the spec thickness (*S*). This moves the specimen away fro X-ray source by an amount *S*/2 and ensures that the of the specimen is over the diffractometer axis.

The device permits the use of the transmission tech at low θ-angles where the reflexion technique is unsatisfa because of varying amount of specimen in the beam, an use of the reflexion technique at high θ-angles wher transmission method is inapplicable. Another ob application of the device is its use with a slower speed for scanning round the circumference of powder lines non-randomly oriented specimens. In this use the spin clamped stationary in the transmission position and Geiger counter is set to the required 2θ angle: the rec then plots a graph of intensity against azimuthal angle.

A tapered plug vacuum valve

By H. R. MOORE, M.Sc., Ph.D.,* Dominion Physi
Laboratory, Department of Scientific and Industr
Research, New Zealand

[*Note received* 28 *September*, 1955]

The use of a right-angle valve at the head of a diffusion is well known and various types have been describe example, by Martin and Hill,[†] and by Riddiford and Lil

As the latter note, the desirability of baffling the inlet calls for the use of a gate-valve. Equally well a valve may be employed. Such plate-type valves also faci rapid isolation of the diffusion pump should a vac accident occur, for their conductances decrease abrupt the closed position is approached.

A valve which compromises between the properties o plate-type valve and the requirement of fine control of speed near the closed position has been built in this labora Its essential feature is the replacement of the usual plate by a tapered plug, in this case O-ring sealed. A figure indicates, the valve was constructed by modifyi large steel conical valve (taper 1 in 5).

The movable tapered plug *A* carries an O-ring in a reta groove. It has enough freedom about the ball *B*, by it is attached to the silver steel control shaft *C*, to ensure it seats correctly against the inner wall of the barrel *D*. control shaft is turned by a wheel handle *E*, its attached s *F* ($\frac{5}{8}$ in. B.S.W.) then running in the internally thre column *G*. The latter is mounted on a cover plate *H* w when screwed on to the barrel, forces the upper plug *I*

---

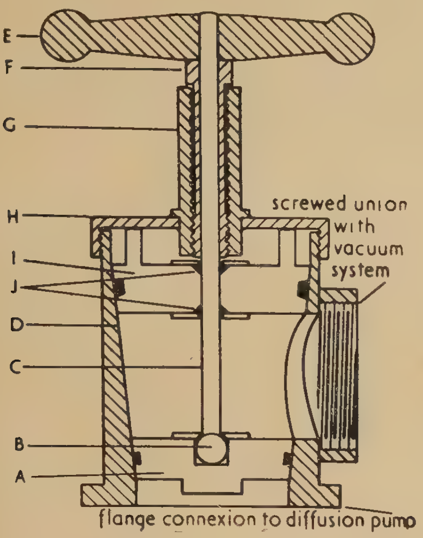
[*] Now at National Research Council, Ontario, Canada.

[†] MARTIN, L. H., and HILL, R. D. *A Manual of Va Practice*, Chapter 4 (Melbourne: University Press, 1947).

[‡] RIDDIFORD, L., and LILLEY, H. *J. Sci. Instrum.*, **29**, p (1952).

permanent O-ring sealed position. Identical O-ring shaft s *J*, at either end of a reamed bearing hole in the upper g, guarantee a reliable atmosphere-vacuum seal on the ving control shaft. The valve is lubricated where necessary h Dow Corning high vacuum grease.

he inertia of the wheel handle is such that giving it a few ns allows the valve to be opened or closed rapidly. On other hand, the gradual taper and thickness of the movable g makes fine control of conductance near the closed ition possible.


E
F
G
H
I
J
D
C
B
A
screwed union with vacuum system
flange connexion to diffusion pump

Simplified sectional view of closed valve

he valve described has been in continual operation during past six months in an apparatus which is initially evacuated a pressure of about 10^{-5} mm of mercury. Gas is then roduced *via* a needle valve, the tapered plug valve allowing pressure to be quickly adjusted to required values in the ge 1–1000 μ of mercury.

The infra-red spectrometer as a non-dispersive instrument

By R. BURT, B.Sc., and G. J. MINKOFF, Ph.D., Imperial College of Science and Technology, London

[*Note received* 29 *September*, 1955]

s difficult to improve the limit of detection of gases with double-beam, infra-red spectrometer, since the major eration is the fractional movement of the mechanical tter. The elimination of some bands, by putting a pure nple or a suitable filter into the reference beam, is only of if the spectra of the gas and of the impurity overlap. th a single-beam instrument, or a double-beam one which asured directly differences or ratios (e.g. Perkin Elmer del 13), the signal due to a particular band can be increased some extent by increasing the amplifier gain and by opening slits, but these are offset by the increased electronic noise l by the decrease in effective absorptivity with decrease in olution. In any case, neither method can be applied to percentage recording double-beam spectrometer. For ny purposes, traces of gases in flow systems are detected using non-dispersive infra-red gas analysers, the sensitivity of which is very high. The authors have found that a satisfactory compromise can be obtained by using the detector of a selective infra-red gas analyser with a double-beam spectrometer.

The detector used was fitted with a gas-filling system, which made it an easy matter to render it sensitive to any required gas. A vibration-free mounting supported the unit in front of the entrance slit of the spectrometer,* all the light entering one of the two detector cells. The other cell was blanked off. This was the only physical alteration to the spectrometer, and only the minimum of effort is needed to remove the detector and to revert to normal conditions. To detect the signal from the cell, the latter was connected, by carefully screened leads, to a head amplifier which applied high tension (30–100 V from a battery) across the condenser plates of the detector, the oscillations being fed into the grid of a type EF 42 valve. The Mumetal box surrounding the head amplifier was also placed on an anti-vibration mounting, and the output was fed into the normal spectrometer amplifier. Two possible modes of operation are now available, depending on the sensitivity required. If the impurity is present in relatively high concentrations (e.g. 5–10%), then the amplifier is used to operate the servomechanism and shutter in the normal manner, the percentage absorption being recorded on the chart without further alterations. When much smaller concentrations are being examined, the amplifier is switched over to difference measurement. The servomechanism is bypassed, the shutter remaining open, and the output of the amplifier, now indicating the difference in absorption between the two beams, is shown on a meter. Maximum sensitivity is then obtained by increasing the gain, the limit of which is controlled by the permissible value of the signal-to-noise ratio.

Using a short cell, length 15 cm, with rocksalt windows (the detector was fitted with silver chloride windows), experiments were made to determine the smallest quantity of gas to produce full-scale deflexion.

Limiting sensitivities

Gas	*Percentage in cell at* 1 *atm for full-scale deflexion*
propane	0·15
acetylene	0·2
ethylene	0·2
propylene	0·2
methane	0·4
nitrous oxide	0·4
carbon monoxide	0·8

The values shown in the table are intermediate in sensitivity between those of the infra-red gas analyser and of the spectrometer. The lower sensitivity relative to the former is due to the much lower fraction of the energy of the source which is eventually collected by the detector. This offsets the higher operating temperature of the Nernst filament in the spectrometer. Although modifications could be made to the optics of the latter, this would defeat the requirement of easy convertibility from one mode of operation to the other.

The authors' thanks are due to the InfraRed Development Co. for supplying the detector and the circuit of the head amplifier. One of them (R. B.) is indebted to the North Thames Gas Board for a Research Fellowship.

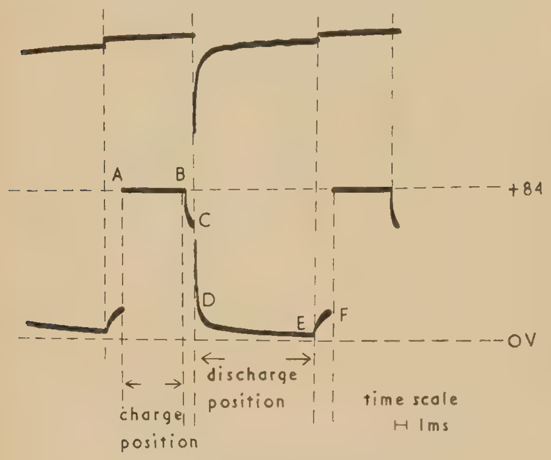
---

* MINKOFF, G. J. *Fuel*, **29**, p. 228 (1950).

Correspondence

A capacitance-resistance hygrometer

I should like to comment on the theory of the Torry capacitance-resistance hygrometer instrument described by Cutting, Jason and Wood on p. 425 of the November, 1955, issue of this *Journal.* The fact that this hygrometer does not behave like a resistive-capacity network can be shown by connecting a cathode-ray oscillograph across the hygrometer and the galvanometer when using the ballistic method of measurement. A high speed relay driven by 50 c/s a.c. was used with a Torry hygrometer to charge at 84 V and discharge through a galvanometer of 185 Ω resistance, the input resistance of the cathode-ray oscillograph was 3 MΩ. The figure shows a tracing of the cathode-ray oscillogram. The downward deflexion of the upper trace is proportional to the potential difference across the galvanometer, and the upward deflexion of the other trace is proportional to the potential difference across the hygrometer which was maintained at 90% r.h. and about 20° C. This anomalous behaviour is observed in:



Trace of cathode-ray oscillogram

(i) the upper trace, by the fact that the discharge current has not fallen to zero by the end of the discharge cycle of 11 ms. The time constant of this element if considered as a resistive-capacity network effectively shorted by the galvanometer should be about 1 ms;

(ii) the lower trace from *B* to *C* confirms the order of magnitude of this time constant as being much less than the discharge cycle. For in the change-over period of 1 ms from charge to discharge, the element shorted by 3 MΩ loses about 38% of its initial charge, corresponding to a time constant of about 2 ms. From *E* to *F* a build-up in the potential difference across the element is observed whilst the relay changes from the discharge to the charge position.

These results clearly demonstrate that a major contribution to the current through the galvanometer is due to d.c. polarization with a time constant of the order of one second and that under the conditions of ballistic measurement the element behaves like a secondary cell with high resistance and capacity.

Meteorological Office, J. MacDowall
Harrow.

In reply to the comment of Mr. MacDowall, may w emphasize that the results given in our paper relate as to measurements taken by an a.c. bridge, with the exce of the aging and transient response effects. The theo treatment is based on these bridge measurements.

Mr. MacDowall's letter brings forward one of a num observations which we intend to discuss in a future munication. In order to provide an adequate reply, necessary to anticipate this paper and mention some q findings.

At the start of our investigation we had observe discharge characteristics of an element by use of a cat ray oscillograph. With the aluminium base positively cha a decay curve, similar to that mentioned by MacDowal observed. This differed from the usual exponential de that the voltage remained finite for a considerable dur i.e. the curve possessed a "tail." We have, therefore, investigated this effect in the following ways.

The discharge curve of elements, and also of pla larger area, were observed on a time scale extende increasing the external resistance. Measurement was both by valve voltmeter and galvanometer. Since the is non-exponential we have not characterized the res a time-constant.

Referring to the equivalent circuit and equations c anodized surfaces, it will be seen that conditions are simp when $R_1 \rightarrow 0$, so that the behaviour of $C_0 + C_2$, (C_0 is small compared with C_2), uncomplicated by pore side e may be directly observed. This was effected experim by placing the surfaces in baths of neutral electrolytes, then formed cathodes contiguous with the oxide su The discharge characteristics were investigated as b With this polarity the resulting current-voltage c correspond closely with those reported by Charlesby(non-porous layers. It appears then that the material a pore base, forming the dielectric of the condenser C_2, be compared in its current-carrying characteristics wit alumina forming barrier layers. In particular, the base thickness can be estimated from the value of the strength *F* obtained from these discharge curves. results are:

		Thickness (*Å*
element	5S7	85
element	6S7	120
plate (area = 72 cm²)		126

All these samples were prepared by anodizing for 30 in 17·5% by volume sulphuric acid at 17° C with a cu density of 40 mA/cm². Since values of the constants and A_- vary greatly for barrier layers,(1) comparison to provide a useful estimate of the pore base cross sec In the case of element 5S7, *A* has a value of 0·0004 μA, consistent with the small cross-sectional area of the bases. Some of these results have previously been report

The "tail" and recharging phenomenon have been cussed by Charlesby (Ref. 1, pp. 540, 541) on the bas space charge effects.

Effect on element characteristics

The behaviour of elements at varying relative humid is essentially determined by the equivalent circuit cited. characteristics of the condenser C_0 mentioned above pr a correction term to the basic theory which is discusse first paper. The magnitude of this correction will depend the conditions of measurement.

listic measurements

n order to avoid ion current, and the consequent further dization with change in the constants involved, small tages—less than 80% of the formation voltage—have been d. The current delivered by the element results from the gration throughout each cycle, of the discharge of C_2 ough a network composed of the external circuit together h the remainder of the equivalent circuit cited. It was reciated throughout that this current may differ appre- bly from that predicted by the equations (1) and (2) in paper.

bridge measurements

hese provide more information than the ballistic measure- nts in that both a current and phase balance are obtained. theory is based on the results of the a.c. bridge measure- nts.

he element formed one arm of a parallel capacitance- istance bridge which was energized by a signal generator h pure sine wave output of approximately 2 V amplitude. dge balance was observed by means of a cathode-ray illograph, balance being taken with respect to the input quency. Under unbalanced conditions no departure of wave form from sinusoidal was observed. The absence harmonics under the conditions of bridge measurement indicate that very little non-linear distortion occurs. Referring again to the Charlesby paper,(1) the ion-current is negligible throughout the a.c. cycle, and since the applied voltage is small, the current voltage characteristics may be represented by equation 3 (Ref. 1, p. 534). Since space charge effects would not be expected to arise in the course of these a.c. measurements, the electrical characteristics of the pore-base material may be represented by a pure condenser C_2 in parallel with a resistance R_2.

We, therefore, consider that the electrical characteristics of porous anodic oxide layers on aluminium at various relative humidities can be accounted for by the equations we have given. These are based on the equivalent circuit shown in our paper.

It is unfortunate that a brief discussion of these topics, which was included in the first draft of the paper(3) was later deleted for reasons of brevity.

Torry Research Station,
Dept. of Scientific and Industrial Research.
C. L. CUTTING,
A. C. JASON

Sir John Cass College,
London, E.C.3.
J. L. WOOD

REFERENCES

(1) CHARLESBY. *Proc. Phys. Soc.* [*London*] *B*, pp. 317, 533 (1953).
(2) BOOKER and WOOD. *J. Electrochem. Soc.*, p. 357 (1955).
(3) JASON and WOOD. *Proc. Phys. Soc.* [*London*] *B*, **68**, p. 1105 (1955).

New books

eodolite design and construction. 2nd Ed. By E. W. TAYLOR. (York: Cook, Troughton and Simms Ltd., 1956.) Pp. 136. Price 20*s*. 6*d*.

hough the theodolite may be regarded by some as a com- ratively simple piece of apparatus, it is nevertheless rarely ssible to discuss it in surveying text-books in the detail ich it deserves. The first edition of Mr. Wilfred Taylor's heodolite design and construction" filled a great gap in blished works by setting out the fundamental principle on ich the theodolite is designed, and amplified this by describ- the many accessories and associated pieces of apparatus. n the second edition the author has added many little provements to the text, and has, for example, given a scription of a method of obtaining "a coincidence image" opposite graduations on a circle, and some notes on the ue of blooming optical surfaces, self-reducing tacheo- ters and equipment used in precise traversing. All odolite users, surveying students and those concerned with repair and adjustment of the theodolite will find this book aluable addition to the book shelf.

G. A. WHIPPLE

truments for measurement and control. By W. G. HOLZBOCK (New York: Reinhold Publishing Corporation; London: Chapman and Hall Ltd., 1956.) Pp. vi + 370. Price 80*s*.

preface somewhat narrows the wide scope inferred by title of this book by saying that it is "concerned with se industrial instruments commonly used for remote ding or remote automatic action within industrial plant." general these limitations are observed. The book is tten by an instrument development engineer for instrument n, and is by no means a text-book on the physical principles instruments. Indeed, the pure physicist will receive some d shocks, as for instance when he finds, on page 2, voltage ined as "the ability of a source of electricity to make a current flow through a resistance." If, however, the reader is prepared to accept the very practical approach, the book has much to commend it as a description of instruments available on the American market. The general scheme of writing is to give a brief outline of the type of instruments under consideration and then to provide much fuller details of one or more commercial instruments by a variety of manufacturers. These fuller descriptions are well done and provide the real substance of the book. The illustrations are also of a high standard, but there is no theory and no mathematics. Even with the reduced scope, some subjects are touched very lightly; thus for instance pH gets less than two pages but measurement of temperature, flow, liquid level and automatic control are treated fully enough to give the reader a good introduction to the practical aspects of these subjects. To those who already have some knowledge of these matters, the book should be of value as giving a review of a cross-section of current American industrial instruments.

M. C. MARSH

Time measurement. 3rd Ed. By F. A. B. WARD. (London: H.M. Stationery Office, 1955.) Pp. vi + 102. Price 6*s*. 0*d*.

This catalogue contains detailed descriptions of nearly five hundred objects which are exhibited in the Time Measurement section of the Science Museum in London. The sections are entitled: primitive and other non-mechanical devices; sundials, nocturnals and perpetual calendars; mechanical clocks; watches and spring-driven clocks; chronometers; Japanese clocks; electric clocks; the quartz crystal clock; stop-watches and chronographs; alarm, striking and repeating mechanisms; gas-controllers and time-switches; time recorders; miscellaneous; list of the more important objects not on exhibition. An index of makers of watches included in the catalogue concludes this edition.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or imp products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Narrow-band filters for use in the ultra-violet spectral region. Barr and Stroud Ltd., Anniesland, Glasgow, W.3.

Narrow-band filters for use in the spectral region 2200 to 4000 Å have been constructed on the same principle as the metal-dielectric filters used for obtaining narrow bands in the visible spectrum.

Silver films are used as the reflecting materials in the visible spectrum and a ratio of peak transmission to background transmission of the order of 300 is obtainable, together with a bandwidth (half peak to half peak) of the order of 80 to 120 Å. Silver fails at wavelengths of approximately 3200 Å since in this region reflectivity falls to a very small value.

It has been found that by special methods of deposition certain other metals, or combinations of metals, can be used as reflectors in the region 3200 Å to approximately 2200 Å and that the ratio of reflexion to absorption is sufficiently high to give a ratio of peak transmission to background transmission of the order of 30, with a bandwidth of the order of 160 Å. Unwanted peaks in transmission are customarily eliminated by absorption, using an auxiliary filter. Unfortunately in the ultra-violet region the number of auxiliary filters available is very small, and this limits the "order" of the interference filter which can be used.

In order to obtain accurate control of characteristics in the non-visible part of the spectrum the manufacturers state that it may be necessary to tilt the filter in the optical system to a maximum of about 25° off axis for maximum transmission at the desired wavelength. Where a tilt cannot be tolerated this should be stated when ordering.

The maximum diameter of filters is 2 in. The manufacturers claim that present experience shows that the filter materials are not affected by ultra-violet light.

Oscillator for very low frequencies. Dawe Instruments Ltd., 99 Uxbridge Road, London, W.5.

The type 442 v.l.f. oscillator, illustrated in the figure, covers the frequency range 0·1 c/s to 10 kc/s with a calibration accuracy of 3%. A valuable feature is the provision of two outputs (each continuously variable to 25 V into a minimum load of 10 kΩ) in quadrature. Such quadrature outputs are of value for testing servo-mechanisms. The oscillator c employs a direct-coupled valve amplifier which is selective by the use of resistance-capacity networks and o negative feedback. The positive feedback circuit, wh necessary to produce self-oscillation, includes a symme diode limiter. The constant-amplitude, rectangular form produced by the limiter is applied to the input c amplifier. Owing to the high selectivity of the amplifie output signal is sinusoidal with a total harmonic distc of 0·3% at the in-phase output and 1% at the quadr output. The limiter circuit thus provides a rapid and matic control of amplitude which is effective down t lowest frequency. The output signals are monitored miniature cathode-ray tube. The valves are grouped tog in a recess in the front panel, so that they are effective side the casing without projecting beyond the front This design is stated to combine full protection with ea access and excellent cooling. Several such oscillators safely be stacked one on top of the other without ri overheating in continuous operation.

T OSCILLATOR

Oscillator with outputs in quadrature. The case is designed to prevent overheating

Phototransistor. Mullard Ltd., Century House, Shafte Avenue, London, W.C.2.

The phototransistor type OCP71, illustrated in the fig similar in form to a conventional low-power junction sistor. For control purposes, the transistor is simply nected in series with a relay coil and a battery of 12 to For most purposes, the base connexion is left floating so only two connexions to the phototransistor are requ This, of course, is one less than in the case of a nc transistor. If it is required to operate the phototrans over a wide range of temperatures, the base electrode be fed with a small positive compensating bias as a mean maintaining the dark current at a low level. The dark cur at 25° C is stated to be not more than 300 μA; the current can be of the order of several milliamps, cc sponding to a sensitivity of 0·3 A/lumen on a sensitive of 7 mm^2. The spectral response has a peak in the infra region at 1·55 μ, but continues into the visible region about 0·5 μ.

Phototransistor (twice actual size)

iority carrier lifetime test set. Baird Associates Inc., 33 University Road, Cambridge, Massachusetts, U.S.A.

s test set utilizes the principle of conductivity modulation. ıt, which is used to inject the excess carriers, is allowed to on an etched semiconductor with two ohmic leads. The ıple is biased by a small d.c. potential. The pulse of light nges the conductivity of the semiconductor sample, with sultant decrease in voltage drop. When the pulse of light emoved from the sample the excess carriers recombine ording to an exponential law. This information is trans- ed through a preamplifier to a cathode-ray oscilloscope. observing the time it takes for the conductivity, as dis- ved on the cathode-ray screen, to decay to half value, the rage life of the excess carriers can be determined. The sed light source used consists of an incandescent lamp, a-red polarizers, double crystal electro-optical shutter the necessary lenses. The unit provides a pulsed light he wavelength region where germanium and silicon are st sensitive. The action of the unit is controlled by a ger circuit, which gives precise control of the duration of light flash. The time taken for the light to be switched off f the order of 0·2 μs. Thus material with minority carrier time in excess of 0·2 μs can be measured.

ium titanate transducers. General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

ium titanate is a ferroelectric material which when properly pared and polarized behaves as a piezoelectric crystal with ery high activity. In the type E barium titanate accelero- ter, a circular disk of barium titanate about $\frac{1}{8}$ in. thick $\frac{3}{8}$ in. diameter is silvered on both sides and sandwiched ween two pieces of brass. One piece forms the base and erminated by a 2 B.A. stud for fixing purposes. The other s as an inertia weight which converts the vibrations of the face to which the 2 B.A. stud is attached to strains in the amic. These strains generate a piezoelectric charge pro- tional to the accleration applied to the base. The potential ınges are collected by a coaxial screened cable and taken a cathode follower to a cathode-ray oscillograph. The elerometer is only $\frac{3}{4}$ in. long, and can easily be attached its stud to any piece of equipment whose vibration racteristics are to be studied. It weighs 11 g (18 g with eening can). The response of the accelerometer to elerations up to 1000 g is linear and its charge sensitivity about 5 pC/g gives a voltage output of about 20 mV/g ng conventional circuitry. The accelerometer will detect record frequencies in the range 20 c/s–20 kc/s and is ted to be accurate to within 10% between 40 c/s and kc/s. An important feature claimed for the accelerometer he construction of the base, which is reduced in thickness t above the mounting stud. This is effective in reducing rious signals due to strains in the object under test, and reduces the effect of transverse accelerations. The nsverse sensitivity is less than 5% of the axial sensitivity, that the direction of vibration can be determined by the sition in which the unit is mounted.

barium titanate vibration strain gauge is available having eral thousand times the sensitivity of the usual wire istance gauge. It responds to alternating strains but not a steady strain. The gauge consists of a thin bar of arized barium titanate with silver electrodes on the two jor faces. The electrode on the lower face is extended ınd one edge on to a small part of the upper face and the ds are soldered on to the two electrodes on the upper face. The under side of the gauge is attached to the object under test by a suitable cement. When the object vibrates, alternating strains in the plane of the gauge produce an alternating charge on the electrodes. The high sensitivity of the gauge is due to the high dielectric constant and piezoelectric activity of barium titanate. An important feature of these gauges is that they can be used to detect vibrations or to excite them by the reverse process of applying an alternating voltage to the crystal. This considerably increases the scope of vibration measurements which can be made on mechanical structures. The gauges have a sensitivity of the order of 0·1 V for an alternating displacement of 1 part in 10^6.

Stroboscope. E.M.I. Electronics Ltd., Hayes, Middlesex.

The rate of flashing of the type 4 stroboscope may be controlled by a mechanically operated contact attached to the mechanism under test, or varied continuously by means of a single control on the top panel. The flashing rate in the self-running condition is continuously variable from 250 to 15 000 flashes per minute in three ranges, the rate being read direct from the calibrated dial. Provision is made to permit the stroboscope to be synchronized to the incoming mains supply. Higher speed mechanisms may be viewed by observing every second, third or fourth cycle of operation and their speed measured by multiplying the direct scale readings accordingly. A mains-driven synchronous reed in the lower part of the lamp reflector provides calibration points at both multiples and sub-multiples of the incoming mains frequency.

Linear, constant-temperature, hot-film anemometer. Lintronic Ltd., 149 Strand, London, W.C.2.

A hot-film anemometer has been designed for turbulent flow measurements over a mean velocity range of 5–1500 ft/s for gas and 0–60 ft/s for fluid flow. The standard ranges can be operated in fluid up to 60° C and in gas up to 500° C. The instrument consists of a sensing probe, a control and linearizing unit and a stabilized power supply. The probe is in the form of a heat-resisting glass rod which has a 30° wedge tip coated with a thin film of platinum. This film is 1 × 0·2 mm and forms one arm of a Wheatstone bridge in the control circuit. A wedge-shaped film is used in preference to the conventional hot wire since it is more robust and has a superior response characteristic at high frequency. The control and linearizing unit has a linear frequency response from 0–100 kc/s ($-\frac{1}{2}$ dB). The current to the bridge is supplied from the output of a direct-coupled amplifier. With suitable feedback the resistance of the film, and hence its temperature, is maintained constant, regardless of the rate at which heat is lost to the surroundings.

The linear relationship between velocity and electrical signal which is furnished by this instrument is obtained by applying the bridge voltage, (which bears the usual fourth root relationship to the velocity), to the control grid of a valve with the inverse bridge characteristic, for a film of the recommended size. The mean velocity is obtained from the d.c. milliammeter on the control panel, multiplied by a suitable scale factor, and the root mean square turbulence is obtained from the reading of an r.f. thermal meter multiplied by a calibration constant.

The h.t. voltage (200 V and −140 V) applied to the linearizing and control unit is obtained from a stabilized power supply with a low hum level.

Notes and comments

User specification for high-temperature X-ray powder diffraction cameras

The user specifications which are prepared by the Equipment Sub-committee of the X-ray Analysis Group of The Institute of Physics are intended to record and make generally known those details of design which crystallographers consider essential in any instrument which they may use.

The existing user specification for high-temperature X-ray powder diffraction cameras was first published in 1950 and a revision is now being considered. Suggestions on any aspect of the design of this type of camera are invited, and should be sent to the Honorary Secretary of the Equipment Sub-Committee (Dr. E. G. Steward, Research Laboratories, The General Electric Co. Ltd., Wembley, Middlesex).

British Chemical Engineering

A monthly journal under the Editorship of Mr. W. E. Dick and devoted to the techniques of chemical engineering applied to industry has been added to the technical journals owned and produced by Heywood and Co. Ltd. The first issue consists of sixty pages of text measuring 8¾ × 11½ in. Besides a leader, there are eleven articles and various trade items, including book reviews. Mr. Barker's article on the potentialities of viscosity control for industrial processes is the one most likely to interest readers of this journal. The new periodical is nicely produced, although we do not see that anything is gained by using a coloured background for some figures.

The annual subscriptions to the new periodical (£1 10*s.* 0*d.* including postage) should be sent to any newsagent or direct to the publishers at Drury House, Russell Street, Drury Lane, London, W.C.2.

Nuclear Power

We announce the establishment of a further periodical devoted to the application of nuclear physics and wish the Editor, Mr. W. Davidson, and his colleagues success. The new periodical is called *Nuclear Power* and is a monthly magazine published by Rowse Muir Publications Ltd., of 3 Percy Street, London, W.1. The subscriptions are £2 2*s.* 0*d.* in the United Kingdom, £3 3*s.* 0*d.* overseas, and $8.0 in the United States and Canada (including postage). This first issue has forty-four pages of text, measuring 8¾ × 11½ in., and is produced in a modernish style, which may appeal to some readers. For instance, the first eight pages are printed on mauve paper; they carry a leader entitled "The Eisenhower deal" and a series of new items under the general heading "Nuclear Power Worldview." Then follows an excellent survey of known processes of heavy water production methods, an account of a gamma dose-rate meter now in commercial production, a write-up of a British firm's radiation research, L. M. Wyatt's account of the production of reactor fuel elements from the ore to uranium metal, the first of a series on reactor physics by J. F. Hill of the Reactor School at Harwell, and some brief items under such headin "survey of equipment," "names in the news" and "ab of patents." The first of a series of detachable data "microscopic cross-sections of elements for thermal neut is included. Very brief abstracts of all the articles in En French, German, Spanish and Russian are added.

Corrosion at bimetallic contacts

A booklet entitled *Corrosion and its prevention at bim contacts* has been published by H.M. Stationery Offic behalf of the Corrosion and Electrodeposition Commit the Inter-service Metallurgical Research Council (Adm and Ministry of Supply). It attempts to provide up-t and reliable information on the subject, primarily fo benefit of designers in government departments and go ment contractors although it should be of conside interest and value to all who are, or should be, conc with metallic corrosion.

The text provides general information about the cond in which bimetallic contacts are most likely to lead to tr some corrosion and also about the means of mitigating effects. This should be read in conjunction with a which indicates the relative corrosion of a range of m when brought into mutual contact and bridged by containing an electrolyte. The metals listed in the tab arranged in two groups. The first is similar to the "sch of potentials" included in many documents; the second g comprises chromium, stainless steel, titanium and alumi all of which develop highly protective oxide films. It i metals in this second group that cause difficulty in attem to predict the behaviour of bimetallic contacts fro schedule of potentials.

Copies of the booklet are available from H.M. Statio Office, price 1*s.* 6*d.*

British Journal of Applied Physics

Contents of the July issue

SPECIAL ARTICLE

The International Temperature Scale and a redefinition of the Kelvin Scal
J. A. Hall.

CONFERENCE REPORT

Summarized proceedings of a symposium on magnetism—London, Sept
1955. By A. C. Lynch and J. Watkins.

ORIGINAL CONTRIBUTIONS

The tensile strength of coal. By C. D. Pomeroy and W. T. A. Morgans.
Apparatus and techniques for the application of a water flow system to the
of aerodynamic systems. By E. F. Winter and J. H. Deterding.
The "ploughing" contribution to friction. By R. T. Spurr.
Klystron oscillator noise theory. By R. L. Bell.
The display of logarithmic Langmuir probe characteristics on a catho
oscillograph. By A. R. Johnston.

NOTES AND NEWS

Correspondence

Measurement of the electrical conductivity of the oxide-coated cathode.
T. B. Tomlinson and R. E. J. King.

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the princip construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Squa London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicati from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Londo E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addre or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable advance. Single parts, so far as available, may be purchased at 10*s.* each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

The Physical Society's Exhibition—London, 1956

By A. J. Maddock, D.Sc., M.I.E.E., F.Inst.P.

The principal new devices, instruments and materials exhibited are briefly described and some of the improvements in earlier models mentioned.

were several features about this year's exhibition of ific instruments and apparatus which were of note and ich general comments might be given. Firstly, it was rst of these exhibitions held by the Physical Society the end of the war when one could look around the s and study the displays in anything approaching rt. It is obvious that a floor area at least as large as wo neighbouring halls used is required for the present er of exhibiting bodies and as any expansion in the try takes place a corresponding increase in area will be d. Secondly, the very drastic pruning by the organizers was evident was well worthwhile and we were spared repetition from year to year of the standard lines of day instruments and apparatus. This is a very necessary n since this exhibition is not intended to be a shop ow for all the goods of all the firms but to show the up-to-date developments. Thirdly, there were more rch items on view than has been the case for many and this was a very welcome aspect.

one time it was possible to report upon this annual ition by dividing it into several sections according to lass of instruments, e.g. optical, electrical, mechanical, It does not seem readily possible to do this nowadays lthough there are still instruments that can be so divided, he application of electronic techniques to instruments h would normally be thought of in separate categories ers this scheme difficult to continue. For example we refractometers and polarimeters with photocells attached iminate the use of the human eye: gas analysis instru- s, formerly chemical with visual detection of the change t are now more electronic in nature: and, on a grander , the automatic indexing of machine tools to prescribed ions in response to data fed into them is being carried y electronics. However, there are still many instruments affected by this trend so in this review we shall attempt sort of classification on the basis of the function an ument is required to perform rather than on subdividing instrument types for, as indicated above, this might to dual classification in many instances. For full details e exhibits the reader is referred to the exhibition hand- , copies of which are still available from The Physical ety, 1 Lowther Gardens, London, S.W.7, price 7*s.* 6*d.* ding postage.

ANALYSIS

industrial processes involving organic chemicals the analysis of these is of importance. One method which w being applied on an increasing scale is that of vapour- e partition chromatography. It is a pity that a new e for this method has not been devised since present-day esses do not depend upon any colour reactions for ting the various fractions. Essentially the method is to a small drop of a liquid mixture into the apparatus, urize it and sweep it by a nitrogen flow through a column with a suitable packing. This latter separates the individual components and, as the more volatile components travel most rapidly they will be swept out of the column first. Thus each component leaves the column at a particular time and passes through a katharometer from which an electrical signal is derived, the amplitude of this depending on the amount of constituent present. The results are presented on the chart of a recording potentiometer as a series of peaks. Though differing in detail and layout, apparatus of this kind was exhibited by W. G. Pye and Co., Griffin and George Ltd., "Shell" Research Ltd., and Metropolitan-Vickers Electrical Co.

A portable instrument for determining the carbon monoxide content of an atmosphere, so acting as detector and alarm, has been devised by the National Coal Board's Scientific Department. The carbon monoxide is oxidized by a suitable catalyst and the temperature rise due to the heat of oxidation is measured by thermistors. The atmosphere is sampled continuously, being drawn through the apparatus by a small pump. The percentage concentration is indicated by a milliammeter, two ranges being provided 0 to 0·1% and 0 to 0·5%: audible and visible alarms operate at a predetermined concentration level. The whole unit is battery-operated and weighs 18 lb.

The automatic laboratories of Baird and Tatlock (London) Ltd. are designed to reduce routine analysis to an automatic procedure when large-scale, continuous, chemical processes are involved. They are equipped to sample and analyse a specific liquid or gas and provide a record of the results, thus releasing skilled personnel for other, less repetitive work. A unit form of construction has been adopted so that selected units may be mounted together to deal with any specific project. Where the size of laboratory or plant is not large enough to warrant the fully automatic laboratory, semi-automatic instruments on similar lines have been devised to provide some degree of automatic working. The principal units at present available can deal with pH measurement, absorption and titration.

Development of the polarograph to improve its sensitivity has been made by the Atomic Energy Research Establishment, Harwell, and the commercial form of this electronic instrument was on the stand of Mervyn Instruments. It differs from the conventional polarograph in that the dropping mercury electrode is held at a constant potential for most of the time: however, at a predetermined time after the fall of each drop the potential is pulsed for $\frac{1}{25}$ s to a value which gradually becomes more negative while a polarogram is being recorded. An increase of sensitivity of at least ten times is claimed even when interfering ions are present in the solution.

Bellingham and Stanley Ltd. have converted a refractometer and a polarimeter to photoelectric detection in place of the human eye. The former is suitable for remote indication of refractive index of clear liquid flowing through a pipe line whilst the latter gives greater accuracy of reading and eliminates observer eye strain.

The three-metre-grating Polychromator made by Hilger and Watts Ltd. will analyse a sample (fitted into an electric spark gap) for up to thirty metallic constituents in less than four minutes and print the result on a paper strip. Light from the entrance slit, after dispersion by the grating, is passed through thirty exit slits, appropriately disposed to receive distinctive spectral lines, and thence to separate photomultiplier tubes the outputs of which charge up separate capacitors. At the end of the integration time the charges of these capacitors are proportional to the intensities of the spectral lines. The charge is not measured directly but the potential of each capacitor is compared, in turn, with a standard capacitor which is charged from a highly stabilized source of potential: a quartz-crystal oscillator times the interval to the point where the potentials become equal and the pulses from the oscillator activate tubes to display the elapsed time and to print the count on a paper strip. The time is thus a measure of the intensity of the spectral line. (A fuller description of this instrument will be found on p. 492 of the December 1955 issue of this *Journal.*)

THERMAL CONSIDERATIONS

The Morgan Crucible Co. Ltd. has evolved a "kit of parts" (Fig. 1) for construction of small laboratory furnaces by the use of silicon carbide resistor tubes for the heating elements and insulating bricks, capable of withstanding 1540° C, which may be cut and drilled with normal hand tools. The resistor tubes are cut in the form of a helix over the central part of each tube: the major part of the resistance, and hence the heating, is thus confined to the central length whilst relatively cool ends are available for making electrical connexions and yet heating element and end connecting section are continuous. These resistors may be run in air up to 1550° C. This firm also showed metal-ceramic bodies (e.g. chromium–alumina, molybdenum–alumina) capable of withstanding sudden changes of temperature and developed to operate from 1200 to 1400° C. Other refractories of fused pure oxides are made by the Thermal Syndicate Ltd. in the form of crucibles, disks, tubes and bricks. Recrystallized alumina can be used up to 1950° C and thoria up to 3300° C this latter being resistant to attack by silica and titanium. Fused zirconia has high thermal conductivity and can be used up to 2600° C.

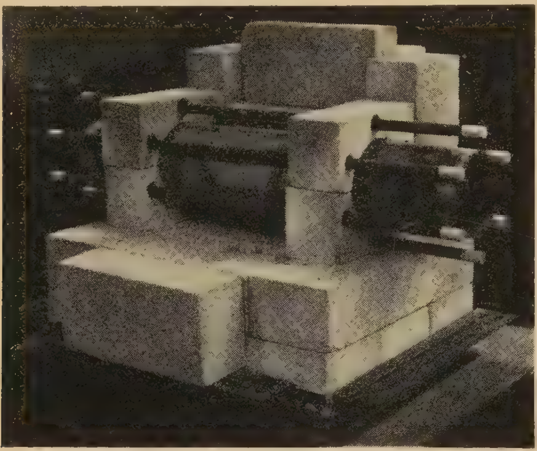


Fig. 1. Laboratory furnace components

Thermocouples of low thermal capacity, and hence high speed of response, have been developed by the Scientific Instrument Research Association. The a and bismuth strips are deposited by evaporation on a thin film of Formvar: the whole device is mou an evacuated envelope. The response is rapid eno "chopped" radiation at about 15 c/s to be resolved.

A study of dropwise condensation on a metal surf been made by the Mechanical Engineering R Laboratory (D.S.I.R.). It was shown that greatly ir rates of heat transfer are obtained in industrial con plant if pure dropwise condensation can be obta distinct from the usual irregular drops entrained in a condensate. The action is brought about by treatn the cooling surface with a promoter which is both repellant and has a high affinity for the metal.

Zone melting as a means of purification was shown new ways. The Services Electronics Research Labo Baldock, bombard a rod to be refined by electrons surrounding filament structure, the rod forming the of a simple diode. The whole is carried out *in vac* temperatures sufficiently high to deal with tungsten, ta and molybdenum can be achieved by this method Chemical Research Laboratory (D.S.I.R.) use the zone technique at much lower temperatures for the purifica organic compounds. Here a cylindrical heater passes down the outside of the column containing the mater an automatic device returns the heater to the top w zone has reached the bottom.

METROLOGY

The extensometer of the Armament Research and D ment Establishment (Ministry of Supply) was devise used on small test pieces, of the order of $\frac{1}{2}$ in. long It is an optical one and has two legs terminating in edges which are applied to the specimen, the distance b the knife edges setting the gauge length: the legs are cor by a flexible hinge of spring steel strip. By suitable p ing of mirrors on the two legs a constant deviation p obtained in effect and the two images, as seen throu autocollimator, from the two mirrors move apart in re to any extension of the specimen: because of the co deviation feature, movement of the collimator will no the distance between the images. The extensometer of Instruments Ltd. employs a differential transformer sensing element so that an electrical signal is directly av for indicating extensions. A stability of 5 μin. and ful deflexion for 100 μin. is claimed.

The National Physical Laboratory (D.S.I.R.) has de an interferometric instrument for checking the caml rolls up to 25 ft in length and between 1 ft and 1 diameter: the instrument has been designed to operat restricted space.

Application of binary digitizing scales to a micro enables readings to 0·001 in. to be obtained rapidl automatically in an electric micrometer. Being digital is no error in the reading (Hilger and Watts Ltd.). Controls Ltd. also showed an analogue to digital con

The very important aspect of setting of machine received attention from British Thomson-Houston Co. and Ekco Electronics Ltd. The system of the former co-ordinate setting and consists of a measuring ba electro-magnetic gauge head associated with each ment: the measuring bar consists of a number of non-fe blocks accurately spaced at 1 in. intervals along a steel The gauge head gives an electrical signal proportional nement between itself and the centre line of an adjacent , on the measuring bar. The head is capable of detecting salinement of 20 μin. A servo-system is used for oning the slides of the machine tool. The system of cond firm is used for automatically controlling a shaft on from a remote point and the devices are called auto- s. One of these, for high precision applications, uses a ade Wheatstone bridge and is accurate to 3 minutes of 10 turns (1 part in 72 000).

might include in this section the instructional theodolite . F. Stanley and Co. Ltd. This instrument has been lly designed to be simple, robust and to take apart so that students may readily grasp the general principles ch an instrument and learn how the theodolite may be ted to reduce instrumental errors to a minimum. Such ice should be valuable in teaching establishments and ve any anxiety about possible damage to a delicate ment.

instrument, known as a photonymograph, for the natic preparation of type matter for use in the pro- on of maps was exhibited by Weapons Research ence) Branch of the Ministry of Supply. The resulting ing, numerals, or symbols are produced on 35 mm ographic paper or film. The master characters are on disks and final characters, imaged on the photographic rial, can be varied in size between 0·05 and 0·5 in. The ing between characters is controlled automatically as a tion of the rear half of one character and the front half e following, thus taking some account of artistic require- ts: if required, the space between characters may be nded, proportionately, to give more open wording. racters are selected manually by rotation of the master and speed of operation is of the order of twenty acters per minute.

simple microbalance has been constructed by the nical Research Laboratory (D.S.I.R.) from a conven- al milliammeter movement with a counterbalanced pan ended from the extended pointer of the meter. Current ugh the meter coil produces a torque in opposition to produced by the weight on the pan and the measure- ts are made by a null method to minimize errors: the current is measured on a separate meter and is an ation of the weight.

equency and time standards of high accuracy and lity are obtained by the use of quartz-crystal oscillators associated electronic frequency-dividers to reduce down ages of ten with the ultimate stage driving a synchronous c. Airmec Ltd. showed the apparatus developed by British Post Office with the exceptionally high daily lity of better than 5 parts in 10^{10}. This unit contains a c/s oscillator using an Essen ring-type crystal in an oven. unit of Labgear (Cambridge) Ltd. is more for general and provides exact frequencies of 100 kc/s, 10 kc/s and s from a 200 kc/s crystal. A built-in radio receiver, tuned to the 200 kc/s carrier frequency of the B.B.C. -wave transmitter, provides a monitoring output for parison purposes: using this and a tuning control on the lator permits adjustment of the source frequency to rt in 10^8. Mullard Ltd. showed a unit on these lines transistors in the crystal oscillator and frequency ers.

LECTRONIC AND ELECTRICAL COMPONENTS

was to be expected semi-conducting devices were well e fore this year, the several manufacturers having reached uction of a number of types forming a range of products. This applies particularly to transistors, now generally available, and to which new types are being added. Firms exhibiting these devices were The British Thomson-Houston Co. Ltd., The General Electric Co. Ltd., Mullard Ltd. and The Plessey Co. Ltd., whilst the Post Office Engineering Department staged an effective demonstration of some effects of ambient temperature on the properties of junction transistors: the different effects due to oxygen and water vapour were particularly striking.

Germanium power rectifiers are highly efficient devices and are available for handling very large rectified currents in a relatively small volume owing to the low power loss, values up to 300 A in a single diode being possible with water cooling. Much effort is being expended on the use of silicon for diodes and transistors as this has an even higher efficiency and, what is very valuable, a considerably lower temperature coefficient. Silicon junction diodes for use in electronic circuits were to be seen from The General Electric Co. Ltd., The British Thomson-Houston Co. Ltd., Ferranti Ltd., Standard Telephones and Cables Ltd., and in power ratings for use as rectifiers for direct currents of 25 to 50 A.

Considerable improvements in selenium rectifier plates have been effected by Standard Telephones and Cables Ltd. A new method of manufacture, employing vacuum evaporation of the selenium, results in greater uniformity between individual plates whilst the increase in purity achieved ensures long life and reliability.

The Radio Research Station (D.S.I.R.) provided a demonstration of thermistors used as circuit elements at low frequencies. Owing to thermal inertia, cyclic resistance variations occur which lag in phase on the current causing them: as a consequence the impedance has an inductive component and this property can be utilized in a low-frequency oscillator.

A novel design of air dielectric decade capacitor, due to H. W. Sullivan Ltd., gives a scale accuracy 100 times better than a variable capacitor of the same range (see Fig. 2). It comprises two decades of air dielectric capacitance and a continuously variable air condenser. The decade consists of

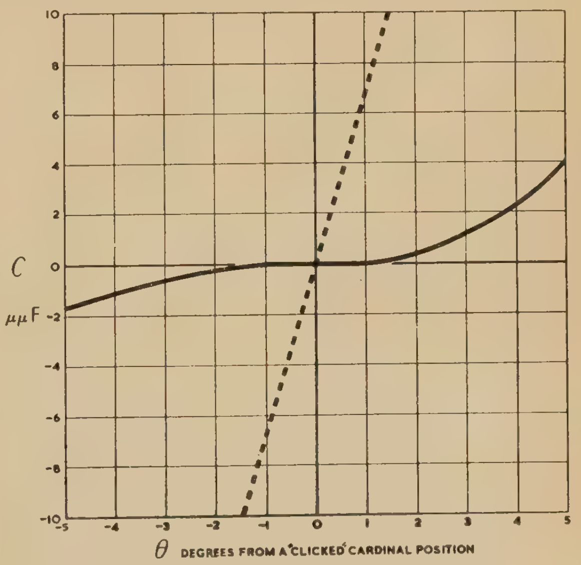


Fig. 2. Curves depicting the virtual elimination of $dC/d\theta$ in the proximity of a "clicked" cardinal position of the decade

——— decade air capacitor
– – – – ordinary variable capacitor

a number of sectors of a variable capacitor introduced with good definition by a "click" device. The arrangement is designed so that only very small edge capacitance changes occur due to any uncertainty in click positioning: the result is a position at each decade position where the rate of change of capacitance with angular position is zero over a finite angular range. Increments of 10 and 100 pF are provided with a range extending to 1110 pF with an accuracy of 0·01%.

A 3 cm reflex klystron of E.M.I. Electronics Ltd. plugs into an external cavity resonator thereby facilitating valve replacement. A single tunable resonator enables a frequency, continuously variable, to be obtained over the range 8500 to 10 000 Mc/s. With other cavities the total range covered is 5000 to 12 000 Mc/s.

ELECTRONIC AND ELECTRICAL CONSIDERATIONS

With the more general availability of transistors, several instruments have been designed around these particularly where small size, light weight and use of batteries is desirable. Amongst these may be mentioned a noise-cancelling microphone with amplifier housed in a telephone handset (Siemens Brothers, Group Research Laboratories); complete encapsulation of electronic circuits (Fortiphone Ltd.); a force and displacement indicator being basically an electrical micrometer with a span of 0·010 in. indicating on a meter ("Shell" Research Ltd.); an audio-frequency oscillator for use with a.c. bridges and an amplifier for use with a bridge balance detector (H. Tinsley and Co. Ltd.); an audio-frequency oscillator (Dawe Instruments Ltd.); a push-pull a.c. amplifier for physiological use, with an input of 1 mV producing an output current of 11 mA into a 1500 Ω load and capable of operating a pen recorder (Edison Swan Electric Co. Ltd.); of particular interest, a portable oscilloscope operating from a 12 V accumulator and using a 3 in. cathode-ray tube (Mullard Ltd.); a distortion-factor meter, and microphone amplifier (Admiralty Signal and Radar Establishment); tuning fork units for providing stable frequency sources [Elliott Bros. (London) Ltd.]; charging unit for quartz fibre dosimeters, and a pocket gamma monitor (Atomic Weapons Research Establishment); 1000 c/s tone generator (Post Office Engineering Department).

Exciting possibilities are opened up by some of the newest alloy semi-conductors which, as a class, have high electron mobility. This is particularly the case with indium antimonide which, as a result, shows a very large Hall effect and high thermal e.m.f. The Services Electronics Research Laboratory, Baldock, has made detailed studies of this material and showed a number of applications in which the Hall effect was used. These include a simple compass, indication of the earth's field being given directly (without any amplification) on a milliammeter; a sensitive magnetometer using the material to explore a magnetic field; and an application to safety devices on railways, the effect being sufficiently marked to operate warning devices in the locomotive cab with the detecting element carried 5 in. above the track, electromagnets placed in the track, and controlled by the signals, creating the necessary magnetic field.

In the testing of servo-systems it is preferable to be able to extend the tests down to frequencies less than 1 c/s. Very-low-frequency generators have been developed by Edison Swan Electric Co. Ltd. (0·01 to 1000 c/s) and The British Thomson-Houston Co. Ltd. (0·1 to 100 c/s). In the latter, a sine wave generator, an electric motor and gear box are arranged to rotate the output shaft at a frequency equal to the desired value required to be generated. This combination drives a two-phase induction generator whose rotor is fed with alternating current, at a frequency of a few k
per second, from a local oscillator. Output is tak
the two stator windings and will consist of the
carrier modulated at the frequency of the shaft r
after passing through separate demodulators "in-pha
"quadrature" components at the low frequency are a
for direct use or for measurement of amplitude an
characteristics. A similar system is employed by the S
Electronic Group Ltd. for analysis of vibration and
balancing of rotating machinery: in this case it is the
furnishing mechanical energy to the vibration test or b
bed which drives the induction generator. The low-fre
generator of Servomex Controls Ltd. can produ
square, sawtooth and triangular waves and also puls

Much effort is being devoted at present to comput
computer components, the latter being particul
evidence. We select for mention two complete con
the one a small table-top analogue computer (Fig. 3)

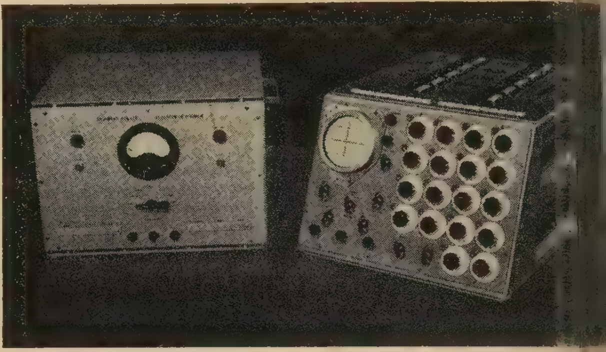


Fig. 3. Small table-top analogue computer

of solving ordinary simultaneous differential equatio
constant coefficients: it may be used for preliminary
investigations and for educational purposes. It is fu
with ten operational amplifiers, twenty coefficient po
meters and cathode-ray tube display facilities. This
unit is made by Saunders–Roe Ltd. A much larger
computer was shown by Decca Radar Ltd. Magnetic
are used in the computing circuits and this has reduc
number of valves to about 200. The input is fed in
punched paper tape whilst the output is to either an e
typewriter or teleprinter. The main store is a magnetic
with a capacity of 4032 words: standard word len
10 decimal or 40 binary digits and the standard wor
under $\frac{1}{2}$ ms.

Another potentially large-scale development in elect
is towards an automatic telephone exchange entirely w
mechanical moving parts. An experimental version—o
lines only—was exhibited by Siemens Brothers
Research Laboratories. The time-division multiplex
of switching is used in which independent connexions be
different telephone subscribers are made by connecting
together at different times over the same wire: the
repetition frequency is 10 kc/s and pulse duration
Junction-type transistor amplifiers and germanium
contact diode gating circuits are used in the modulator
demodulators thus leading to low power consumptio
keeping the size to a minimum.

Recording of data and its subsequent analysis is of
importance especially when the information is being f
at a rapid rate or from a multiplicity of sources. M
Instruments has designed a unit (Fig. 4) for the Minist

ly which is a complete system for simultaneous recording e outputs of seven transducers of any type: the informa- is recorded on magnetic tape and simultaneous presenta- of the resulting waveforms is made on a chart by means n recorders. Automatic analysis of the frequency and litude of the wave over a range of 1 to 3000 c/s may be le: any portion of the waveform of between $\frac{1}{2}$ and 30 s ation may be selected for analysis.

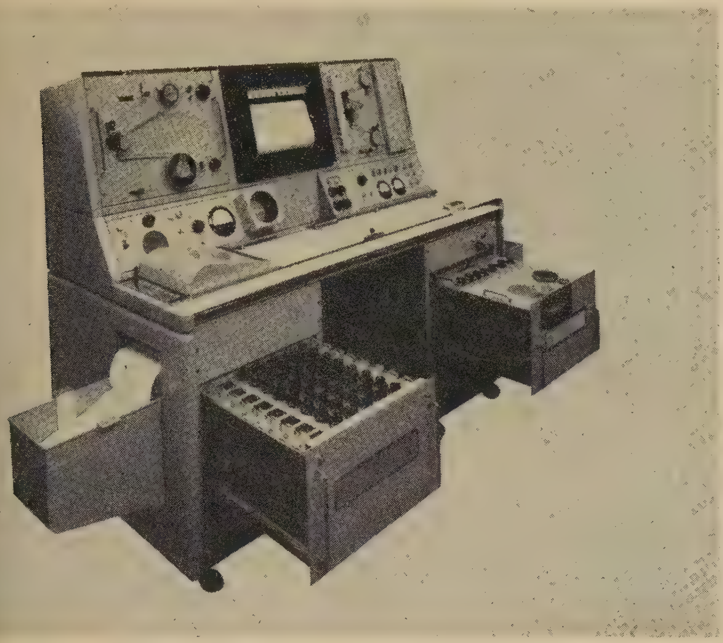


Fig. 4. Multichannel data recorder and analyser

he National Physical Laboratory (D.S.I.R.) has developed udio-frequency wattmeter for the range 50 c/s to 20 kc/s forming to precision grade of the British Standards itution. The field- and moving-coils of a nickel–iron d dynamometer movement are energized from the outputs of two negative-feedback amplifiers. Current shunts and voltage divider ($1000\,\Omega$/V), with small time constant, provide inputs to the amplifiers. Switching can be provided to enable consecutive determination of current, voltage and power to be made: mains voltage variations up to 10% do not affect the accuracy of the instrument. Commercial versions have been made by Cambridge Instrument Co. Ltd., and H. Tinsley and Co. Ltd.

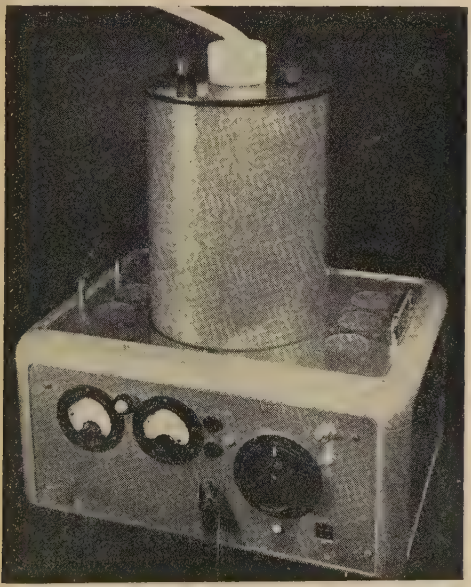


Fig. 5. Compact high voltage d.c. generator

Two extremely compact and useful high-voltage d.c. generators have been devised by the Atomic Energy Research Establishment, Harwell. These use a multi-stage oil-immersed Cockcroft–Walton generator operating at a frequency of 65 kc/s, corrected for voltage drop and stabilized against load variations: the output voltage is controlled by variation of the power supplied to the oscillator. One unit (Fig. 5) supplies 80 kV at 0·5 mA and the other 250 kV at 0·75 mA.

OPTICAL CONSIDERATIONS

Interference filters, both narrow- and wide-band, and dichroic mirrors are finding a wider field of application and the latter are used in at least one system of colour television. Whilst mentioning this latter subject we wish to congratulate the Physical Society Colour Group on an excellent presentation of the principles of colour television: this was a deservedly popular exhibit and many individuals and organizations had contributed in preparing the exhibits.

Barr and Stroud Ltd. had several types of filter of improved performance including some utilizing aluminium, chromel and titanium dioxide, the latter having the high transmission value of 97%. Standard Telephones and Cables Ltd. had absorption filters of lead telluride transmitting beyond $3{\cdot}4\ \mu$ and lead sulphide beyond $2{\cdot}4\ \mu$: to reduce any interference band with thin layers and to increase the transmission level the filters are "bloomed."

For the production of metal oxide films by sputtering or evaporation Edwards High Vacuum Ltd. has designed a new coating apparatus in which such films can be deposited in sequence or coincidentally. One or more pairs of V-shaped electrodes are used mounted above a plane, rotary work table and one of each pair functions as a cathode on alternate cycles: rectification of the h.t. supply is thus unnecessary.

The new research microscope of R. and J. Beck Ltd. includes built-in illumination, enlarged movements for the mechanical stage enabling full scanning (3 × 2 in.) to be obtained, actuating heads for the stage and focusing controls are all below stage level for comfort in operation, and two degrees of focusing are provided with independent actuating heads on opposite sides of the limb. In the metallurgical microscope (Fig. 6) of Cooke, Troughton and Simms Ltd., the system is inverted so that the under surface of the specimen, resting on the stage, is the one under examination. The focusing controls are situated near the base of the instrument, built-in illumination is used, and the circular, rotatable and centring stage is of the sliding type, one hand only being required to impart any horizontal movement to the smoothly operating stage: the coarse focusing movement adjusts the height of the stage. C. Baker of Holborn Ltd.

had an interference microscope for studying surface finish. The two interfering beams are only separated over a short distance and the reference surfaces are an integral part of the objectives: objectives are available adjusted for specimens of different reflectivities. A gliding stage, as already described, makes positioning of the specimen very easy and smooth.

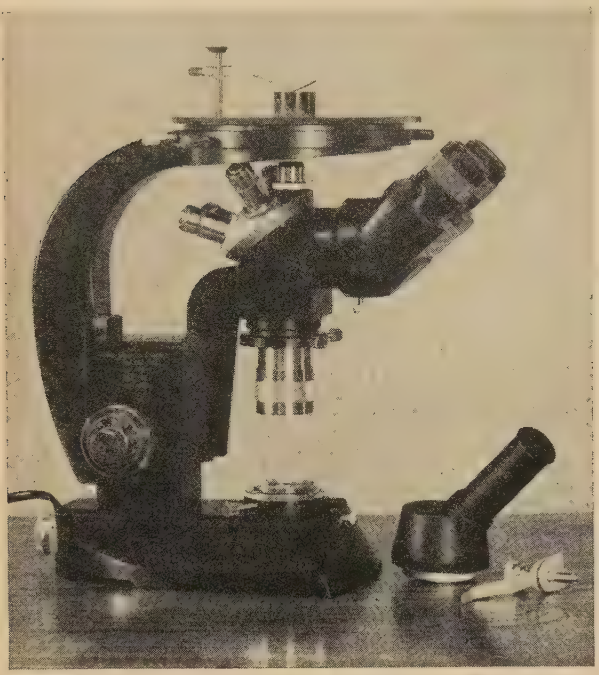


Fig. 6. Inverted metallurgical microscope

A novel method for studying the response function of lenses was exhibited by the Royal Aircraft Establishment (Ministry of Supply). The apparatus scans the image, formed by the lens, of a luminous point source and thus explores the fine structure of the image. It is considered by the designers that the response function obtained by this device might supersede resolving power as a criterion of optical performance.

On the research side a most interesting study is being made at the University of Reading of involuntary eye movements. In most of the work the subject wears a contact lens fitted with a stalk to which small mirrors are attached: light is reflected from these mirrors to a recording camera.

MISCELLANEOUS

Instrumental determinations of the rheological properties of materials are not generally easy to make. An improved version of a rheogoniometer, developed from a design of the Ministry of Supply by Farol Research Engineers Ltd., makes goniometric measurements of the forces and displacements at various points of the flowing material across three mutually perpendicular planes and records these as functions of time by means of a cathode-ray tube or pen recorder. Vibrational shearing forces of various frequencies and amplitudes can be superimposed on a steady shearing motion. Sudden changes in the rate of flow can be made to study the build-up and relaxation of stress.

It seems, perhaps, a far cry from nuclear precession to measurement of the earth's magnetic field but the relatively simple apparatus of the Signal Research and Development Establishment (Ministry of Supply) provides the connexion. The protons in a sample of ordinary water are first po by a magnetic field approximately at right angles direction of the earth's field: this polarization is then re to zero very rapidly with the result that the macro magnetization vector remaining precesses freely abo earth's field direction for several seconds, the expone decaying signal being picked up by a suitably oriente The method needs no calibration nor is any care nec in setting up the measuring head itself, which is a rel robust unit.

The ability of indium to cold weld under pressure at temperature has been utilized by the Admiralty Signa Radar Establishment for connecting sections of wave together. The joint is water- and air-tight and can pressurization up to the normal values used in the wave itself.

Porous stainless steel, as developed by the B.S.A. C Research Centre, has interesting possibilities and a nu of filters made from it were shown: these included B funnels, aerators, beaker filters. The material is ava in a wide range of permeabilities and pore sizes and applications quoted are flame traps, pressure snubbe protection against shock waves and one-way fluid valve

CRAFTSMANSHIP AND DRAUGHTSMANSHI COMPETITION

One of the most interesting features of this exhibit always the entries for the annual Craftsmanshi Draughtsmanship Competition held in conjunction wi exhibition. We cannot do better than call attention t Judges' Report and the list of prize winners that are p below.

Judges' Report

The Judges are heartened by the fact that the inter this competition is not only maintained, but increases y Last year there were 130 entries for the competition an year 157.

Although there were several outstanding individual in Class I, "Scientific instruments and components," general standard was possibly not up to that of pre years. Present trends in the instrument industry were pe responsible for the increased number of examples of concerned with micro-wave measurement. Unfortunate high quality of workmanship demanded by this type of is not often apparent from the external appearance. Th an increasing tendency for competitors to submit co pieces of equipment which are standard products of employers, and more evidence of original thought initiative on the part of competitors would be welcome, at the cost of simpler examples of workmanship, pro that these gave sufficient scope for displaying true c manship.

In the main, entries in Class II, "Tools and gauges," of a high standard both in Junior and Senior sections there was a small percentage which did not give suffi scope for judging the candidate's ability as a crafts Conversely, certain entries in the Junior section were a ambitious, the accuracy being incompatible with the su chosen. Nevertheless, the general impression is very gr ing regarding the future supply of craftsmen.

There were again only four entries in Class III, "Op components and systems," a number similar to that of 1 It is regrettable that the number of entries to this partic class continues to be small. None the less, the standar craftsmanship of the work submitted is undoubtedly order. In spite of the small number of competitors in section, it would appear undesirable to remove this class the competition for by its continuance the craftsmanship lved in making high quality optical work is kept alive.

he usual high standard of the glass apparatus submitted Class IV was again maintained and the Judges were very ressed with the manipulative skill and technical ability of three prize winners. The difficulty is experienced each in finding a common basis on which to assess the relative of entrants submitting examples of work in such different erials as silica and glass. The small number of entries) in silica precludes the division of Class IV into two ions, but it would be very satisfactory if the number of ies increased in future.

here was a marked increase in the number of entries this year in Class VI, "Draughtsmanship," but as they were more evenly distributed between the Junior and Senior sections it was decided not to split the sections as we have on occasions in the past. The standard of draughtsmanship was extremely high, particularly in the Senior section, where great difficulty was experienced in selecting the winning entries; in fact, two second and two third prizes were recommended by the Judges. Although the standard of draughtsmanship was equally high in the Junior section no difficulty was experienced in selecting the winning entry, as this was, in the opinion of the Judges, an outstanding piece of work on the part of the competitor. Many points were lost, particularly among the entries in the Junior section, by the competitors tackling simple jobs which often limited the scope of the competitor to show his ability in draughtsmanship.

Craftsmanship and Draughtsmanship Competition

PRIZE LIST

Scientific instruments and components (Junior grade)

t prize: D. TAYLOR (National Physical Laboratory). Adjustable ounting for a Kösters-type prism.

ond prize: E. F. NETTMAN (Marconi's Wireless Telegraph Co. td.). Screened attenuator.

ourable mention: R. W. BURRAGE (Mullard Equipment Ltd.). ramme balance and stand.

ourable mention: M. P. THOMAS (National Physical Laboratory). pparatus for obtaining impressions of the profiles of prisms.

Scientific instruments and components (Senior grade)

t prize: J. R. WILSON (Marconi Instruments Ltd.). Lightweight tereotaxic instrument.

ond prize: M. BEAUMONT (Services Electronics Research aboratory). Micro manipulator.

rd prize: M. G. BELSHAM (Marconi's Wireless Telegraph Co. td.). Part of Q-band reciprocating standing-wave indicator.

nourable mention: R. W. THROSSELL (Marconi's Wireless Telegraph Co. Ltd.). 3 cm standing-wave indicator.

nourable mention: M. R. BAKER (George Kent Ltd.). Pneunatically operated computing mechanism.

ecial prize: G. TOOGOOD (Radar Research Establishment). Single prism monochrometer.

Tools and gauges (Junior grade)

st prize: D. W. BEDFORD (Ministry of Supply, A.I.D. Laboraories). 5 in. sine bar.

cond prize: M. BENNETT (Services Electronics Research Laboratory). 0–4 in. bench micrometer.

ird prize: W. H. BROCKBANK (George Kent Ltd.). Precision screw diameter and radius measuring device.

nourable mention: M. W. WILLIS (Cambridge Instrument Co. Ltd.). Simple instrument maker's dividing head.

nourable mention: D. M. MURRAY (Girling Ltd.). Engineering steel square.

nourable mention: D. G. HARRIS (Standard Telephones and Cables Ltd.). Sine bracket.

Tools and gauges (Senior grade)

st prize: J. B. ATKINSON (George Kent Ltd.). Precision 5 in. sine square.

cond prize: K. J. CROCKFORD (Mitcham Works Ltd. and Mullard Radio Valve Co. Ltd.). Experimental pierce, shear and blank ool.

ird prize: E. SLATER (British Thomson-Houston Co. Ltd.). Vernier height gauge.

nourable mention: M. N. BUCKINGHAM (Services Electronics Research Laboratory). Glass sealing jig.

nourable mention: B. P. CLARKE (Standard Telephones and Cables Ltd.). Sine centres for measuring angles and tapers between centres.

Honourable mention: D. W. TURNER (Standard Telephones and Cables Ltd.). Top slide of co-ordinating device for locating centres for boring.

Honourable mention: D. P. A. GIBSON (Ministry of Supply, A.I.D. Laboratories). Universal vice.

Optical components and systems

First prize: M. L. HAMMOND (National Physical Laboratory). Beam splitting prism of Kösters-type.

Second prize: I. PHILLIPS (Hilger and Watts Ltd.). Liquid cell for Rayleigh refractometer.

Blown-glass and silica ware

First prize: D. B. TUCKWELL (E.M.I. Research Laboratories Ltd.). Two-stage mercury diffusion pump.

Second prize: A. J. JONES (Research Laboratories, General Electric Co. Ltd.). Two-stage pump.

Third prize: A. G. THOMSON (E.M.I. Research Laboratories Ltd.). Oil diffusion pump.

Honourable mention: D. J. KEAST (British Thomson-Houston Co. Ltd.). Ebulliometer.

Honourable mention: C. W. LEWIS (Electronic Tubes Ltd.). Integral 2 in. mercury diffusion pump and liquid air trap.

Sections of instruments, functional scale models of scientific interest and patterns

First prize: D. N. FRAKES (Standard Telephones and Cables Ltd.). Chain driven, sawing-off machine.

Draughtsmanship (Junior grade)

First prize: D. J. STEVEN (E.M.I. Engineering Development Ltd.). Correction gearbox and details.

Second prize: M. H. THORNHILL (E.M.I. Engineering Development Ltd.). Indicator, gearbox assembly and details.

Third prize: P. I. BUNCE (British Thomson-Houston Co. Ltd.). Reduction unit assembly.

Honourable mention: J. N. MANLEY (E.M.I. Engineering Development Ltd.). General assembly and details of drive unit.

Draughtsmanship (Senior grade)

First prize: T. W. HIPKINS (British Thomson-Houston Co. Ltd.). Motor-operated barring gear.

Second prize (shared): K. A. BATTLE (E.M.I. Engineering Development Ltd.). General assembly and details of servo gearbox. D. T. J. THOMAS (E.M.I. Engineering Development Ltd.). Gearbox and contact assembly and details.

Third prize (shared): T. M. LAWMON (E.M.I. Engineering Development Ltd.). Assembly and details of data unit. J. A. DAY (Standard Telephones and Cables Ltd.). Detail and assembly drawing of wave-guide switch unit.

Silvanus P. Thompson Prize

First prize: D. P. A. GIBSON (Ministry of Supply, A.I.D. Laboratories). Universal vice (drawings and instrument).

Honourable mention: J. P. SIMMS (E.M.I. Engineering Development Ltd.). Large springbow and trammel compasses (drawings and instrument).

An automatic device for fixing thick nuclear emulsion layers

By G. THURO, Dipl. fiz., The Ruder Bošković Institute, Zagreb, Yugoslavia

[*Paper received* 27 *March*, 1956]

A simple device for fixing thick nuclear emulsion layers has been constructed; it keeps the fixer flowing first one way and then the other through the box in which emulsion layers are kept. The flow of the fixer can be made as slow as required which is specially useful for continuous dilution of the fixer. The fixer runs from one flask, through the box, into another flask, and back, being driven by the pressure of the water mains. The direction of flow is automatically reversed by an electromagnetic switch, when the water in one of the flasks makes contact between a pair of electrodes.

The fixing of thick nuclear emulsion layers (400–600 μ) requires a continuous change of the layer of fixer above the plates. Thus the products of the dissolved silver halides are removed and fresh fixing solution, that has a greater ability to dissolve further quantities of silver bromide, is brought to the plates. The result is faster and more thorough fixing.

Devices used for such fixing usually work with the aid of (i) rotating pumps,[1,4] (ii) mechanical movement of the box in which the plates are kept, (iii) a timing system that lets fresh fixer into the tank every few minutes,[2] or (iv) passage of nitrogen bubbles through the fixer[1] to stir it. The device described in this paper differs essentially from these and has some advantages.

Fig. 1 shows a diagram of the device. It is placed in a thermostat that keeps a constant temperature of 5° C. The switch S (Figs. 2 and 3), is connected to the water mains and conducts the water alternately to the container B_1 or B_4.

Let us begin our observation at the moment when the flask B_1 is connected to the mains, as shown in Fig. 1. The water level in flask B_1 rises slowly and, by increasing the pressure in flask B_2, drives the fixer out of B_2, through the bo containing the emulsion layers L, into the contain while the water is driven out of B_4 through S into the drai

When the water level reaches the upper pair of c electrodes (E_1, E_3), and touches E_1, it lets alternating cu flow through the relay R_2 (Fig. 4). The contacts 1 and thus connected to contacts 3 and 5, and the electric circu the electromagnet M is closed (Figs. 2 and 4). The ele magnet M is constructed and works like a galvano with a moving coil but instead of a torsion wire it has bearings upon which the rotor N moves. The magnetic then turns the rotor N (Fig. 2) of the electromagnet th 50° (from the point 25° to the left, to the point 25° t right of the position of maximum torque), and is st there by two bars P (Fig. 2).

Thus the switch S is turned from the position (Figs. 1 and 3) into the position Y–Y, and connects now container B_4 to the water mains, and B_1 to the drainage. B_4 the water level rises, and the pressure drives the from B_3 through K into B_2, and from B_1 the water goes

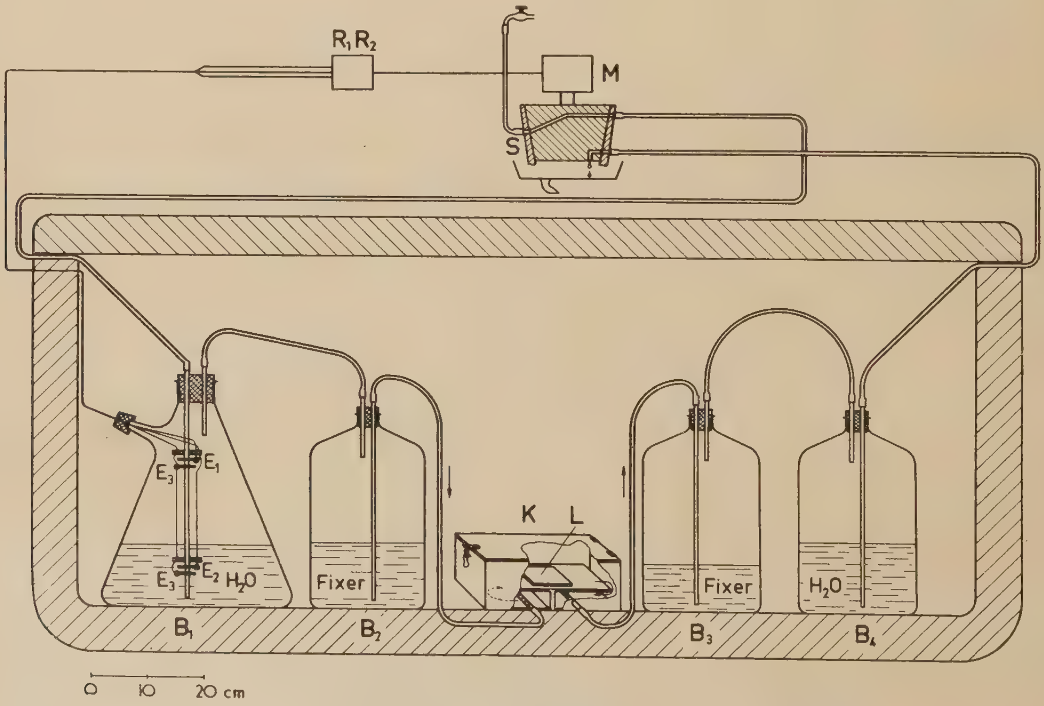


Fig. 1. Automatic device for fixing thick nuclear emulsion layers

ugh S to the drainage. As soon as the surface of the r loses contact with the electrode E_1 in B_1, the relay R_2 free its armature which connects the points 1 and 2 to d 5 and thus breaks the current flowing through the romagnet M.

he water level falls and, when it loses contact with the trode E_2, breaks the circuit of the relay R_1. The armature

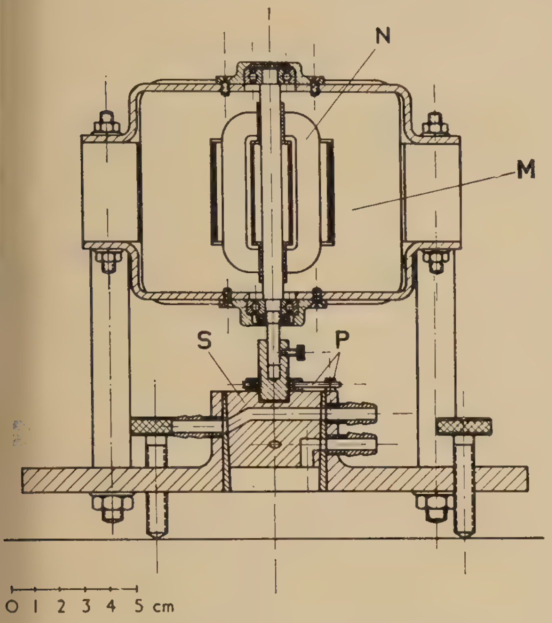


Fig. 2. The electromagnetic switch

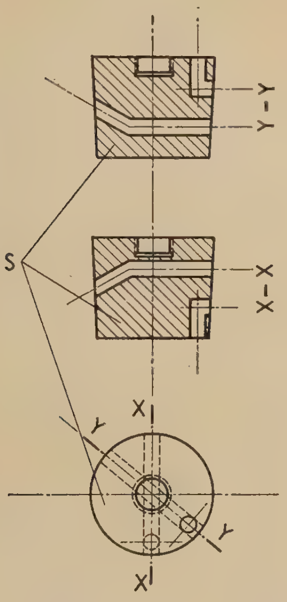


Fig. 3. Two positions of the electromagnetic switch

R_1 is set free and falls from the position 1 to position 2 thus again lets current through the stator and rotor of M, ch are connected in series (Fig. 4).

he magnetic field in M turns the rotor back through 50°— the direction of the current through the stator has remained same, while in the rotor it is now reversed—and thus rns S into position X–X. The water level in B_1 again starts to rise and, as soon as it reaches E_2, the relay R_1 breaks the current through M. In this way the fixer is driven to and fro.

The velocity of flow can be regulated by opening the water tap, and can be reduced to one drop per second. This is specially useful for continuous dilution of the fixer before washing the plates, which is required in order to avoid distortion.(1) Dilution of the fixer is easily achieved by adding water or a 2% solution of sodium sulphate(1) to one of the containers B_2 or B_3, without disturbing the box with the emulsions.

A further advantage of this apparatus is that the direction of flow of the fixer is automatically reversed after some time (one to two hours, depending on the velocity and quantity of fixing solution). Thus symmetrical fixing is assured. This is not the case with one-directional flow, since the fixing is faster at the end of the plate which is turned towards the stream and so causes distortion. Since the same fixer remains in the system for about six hours before it is changed, it will contain dissolved silver bromide. This silver bromide, however, is a protection against "corrosion" of silver grains and does not affect the rate of fixing appreciably.(5)

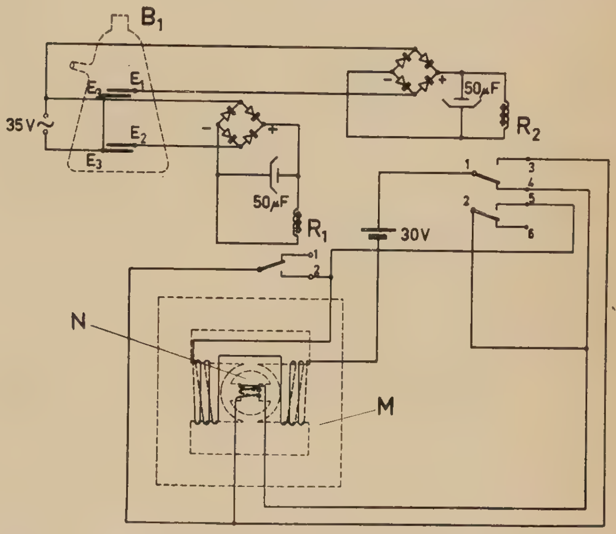


Fig. 4. Circuit of the device for fixing thick nuclear emulsion layers

Three wires lead from the relays R_1, R_2 through a rubber plug to the electrodes E_1, E_2 and E_3 in B_1 (Fig. 1). They pass tightly through the plug which is stuck with Araldite on to the side tube of B_1, so that B_1 can hold a small pressure.

The electrodes are copper plates, placed in a horizontal position so that they make and break the contact with the water surface as briskly as possible. The surface of the electrodes (about 5 cm^2 each) is large enough for the resistance of the water between them to be as low as is necessary to pass the current needed. Each electrode is fastened to one of the two rubber plugs through which the longer glass tube of B_1 is driven. Thus the necessary stability is attained. The distance between the upper and lower pair of electrodes, and thereby the amplitude of the oscillation of the fixer, can easily be regulated by sliding the electrode holder up or down.

To avoid trouble with electrolysis, alternating current is used between the electrodes, but as the relays available operate on direct current, a full-wave rectifier is used to make the necessary conversion (Fig. 4). Both relays work on 12 V and 30 mA.

The electromagnet works on 30 V d.c. and 0·6 A (18 W). The sliding surface of the switch S is lubricated with grease to diminish the friction. Switch S should not be placed much higher than the containers B_1–B_4, since the pressure in the system would then be unnecessarily high. The design of the box K (made of stainless steel) allows laminar flow over the emulsions. The containers are all filled with nitrogen, in place of air, because this is one of the factors that help to avoid corrosion of silver grains in the emulsion.(3)

ACKNOWLEDGEMENTS

Thanks are due to Prof. Paić for his interest and encouragement.

REFERENCES

(1) BONETTI, A., DILWORTH, C. C., and OCCHIALINI, C *Bull. Cent. Phys. Nucléaire, Bruxelles*, **13b** (1951)

(2) BIRGE, R. W., KERTH, L. T., RICHMAN, C. H., D. H., and WHETSTONE, S. L. Berkeley, Cali Radiation Laboratory UCRL-2690 (1954).

(3) THURO, G., and PAIĆ, M. *Étude de la diss des grains d'argent des plaques nucléogra ("nucléaires") épaisses dans le fixateur.* Submit *Nuovo Cimento.*

(4) STILLER, B., SHAPIRO, M. M., and O'DELL, F. W. *Sci. Instrum.*, **25**, p. 340 (1954).

(5) MEULEMANS, G. *Nuovo Cimento*, **12,** Suppl., (1954).

Composite quarter- and half-wave plates

By Prof. W. H. J. CHILDS, D.Sc., F.Inst.P., F.R.S.E., Heriot-Watt College, Edinburgh

[*Paper received* 2 *March*, 1956]

It is well known that, within certain limits, a quarter-wave plate may be made from two suitably oriented cellophane sheets.(1, 2) An attempt to construct such composite plates showed up some of their interesting peculiarities. These are discussed in the present paper, which also gives constructional details of quarter- and half-wave plates and extends the theory to include two- and three-component wave plates of any delay. General expressions are developed to cover all these cases; in the case of triple-sheet combinations it is shown that it is possible to neutralize the rotation of axes which is unavoidable with two-component plates and to produce composite plates having all the properties of simple plates. To assist the design and assembly of composite plates, tables of constructional constants for double and triple quarter-wave plates, and triple half-wave plates are included.

THEORY

The conditions under which two doubly-refracting sheets may be combined to produce circularly polarized light have been obtained by Jessop and Harris.(2) From their results it is not clear whether the composite plate is merely a device which in certain circumstances will produce circularly polarized light, or whether it is indeed a true quarter-wave plate. Using a direct method similar to, but more general than that of Jessop and Harris, it is simple but tedious to show that the composite plate is a quarter-wave plate, but with a peculiarity which a simple quarter-wave plate does not possess. If a simple plate is set up to produce circularly polarized light and is then rotated $\pi/4$ about the light direction as axis, the transmitted beam will then be plane polarized, with its electric vector parallel to that of the incident beam. This is not the case with the composite plate; if this is rotated $\pi/4$ from the setting which produces circularly polarized light, the transmitted beam is also plane polarized but with its electric vector at an angle to that of the incident beam. In all other respects it behaves as a quarter-wave plate.

An investigation of this behaviour, using a more formal but elegant and powerful matrix method suggested by the author's colleague, W. Stewart Brown, has resulted in general expressions for composite plates of any phase delay.

Two conjugate axes are defined, one on the incidence face, the other on the emergence face of the composite plate, such that light plane polarized with its vector parallel to the incidence axis emerges plane polarized with its vector parallel to the emergence axis. Perpendicular to these is a second set of conjugate axes with the same property. The difference associated with passage through the com plate is smaller for one set of axes than for the other, are called "effective fast axes." The phase difference bet the two sets of axes is called "the effective phase differen the composite plate."

Defining the angle between the fast axis of the first ponent sheet, and the effective fast axis of the composite on the face on which the light is incident as θ_1, the between the fast axes of the two components as θ, the between the fast axis of the second component sheet, the effective fast axis of the composite plate on the face which the light emerges as θ_2, the angle between the effe fast axes of the composite plate as ϕ, the phase diffe produced by passage through the first component as δ phase difference produced by passage through the se component as δ_2, and the effective phase difference o composite plate as Δ, the following relationships then

$$\cos 2\theta_1 = (\cos \delta_2 - \cos \delta_1 \cos \Delta)/\sin \delta_1 \sin \Delta$$

$$\cos 2\theta = (\cos \delta_1 \cos \delta_2 - \cos \Delta)/\sin \delta_1 \sin \delta_2$$

$$\cos 2\theta_2 = (\cos \delta_1 - \cos \delta_2 \cos \Delta)/\sin \delta_2 \sin \Delta$$

together with

$$\sin 2\theta_1/\sin \delta_2 = \sin 2\theta_2/\sin \delta_1 = -\sin 2\theta/\sin \Delta$$

If, as most likely will be the case, both parts of the posite plate are to be cut from the same sheet, then it fol

δ_1 and δ_2 are the same and can be put equal to δ, hat:

$$\cos 2\theta_1 = \cos 2\theta_2 = \cot \delta(1 - \cos \Delta)/\sin \Delta \qquad (5)$$

$$\cos 2\theta = (\cos^2 \delta - \cos \Delta)/\sin^2 \delta \qquad (6)$$

$$\sin 2\theta_1 = \sin 2\theta_2 = -\sin 2\theta \sin \delta/\sin \Delta \qquad (7)$$

or a quarter-wave plate $\Delta = \pi/2$ so that for this case the essions reduce further to:

$$\cos 2\theta_1 = \cos 2\theta_2 = \cot \delta \qquad (8)$$

$$\cos 2\theta = \cot^2 \delta \qquad (9)$$

$$\sin 2\theta_1 = \sin 2\theta_2 = -\sin \delta \sin 2\theta \qquad (10)$$

ce θ is the relative orientation of the component sheets, the only angle which matters in the construction of the e; θ_1 and θ_2 determine the orientation of the plate when ise.)

nly values of δ within certain limits, depending on the ie of Δ, will satisfy equation (6). The lower end of this ge of values for δ is $\Delta/2$, the upper end $[\pi - (\Delta/2)]$, from ch it follows that, to construct a quarter-wave plate from itical sheets they must be taken from material with a se retardation lying between $\pi/4$ and $3\pi/4$. For a $\lambda/8$ e the range available would be $\pi/16$ to $7\pi/16$, whilst for alf-wave plate the limits coincide at $\pi/2$ and the only ition is the trivial one of two superposed quarter-wave ets. It follows that a composite half-wave plate must be le up from two composite quarter-wave plates in series.

s a further consequence of these expressions it follows t by combining two quarter-wave plates at an appropriate le, a composite plate may be obtained with any desired se delay between zero and π. Because in this case δ_1 and oth are $\pi/2$, expression (1) reduces to

$$\theta = (\pi - \Delta)/2 \qquad (11)$$

l expressions (1) and (3) to

$$\theta_1 = \theta_2 = \pi/4 \qquad (12)$$

is with $\theta = \pi/8$ a $3\lambda/8$ plate results, with an angle $3\pi/8$ ween the effective fast axes on the incident and emergent es; with $\theta = \pi/4$, a $\lambda/4$ plate results, with an angle of $\pi/4$ ween the effective fast axes; and $\theta = 3\pi/8$ gives a $\lambda/8$ te, with an angle of $\pi/8$ between the effective fast axes.

PLATE CONSTRUCTION

teps in the construction of a composite plate are (*a*) the ction of suitable material, i.e. the determination of axes l phase delay, (*b*) the actual manipulation and assembly of sheets.

ection of material

The determination of axes is a simple matter of rotating a et of the proposed material between crossed Polaroids til extinction occurs, when the axes are parallel to those the Polaroids. To discriminate between the fast and slow es is not such an easy matter, but fortunately it is unessary unless the composite plate is required to produce cifically right-handed or left-handed circularly polarized ht. Nearly all cellophane is doubly refracting, and in all samples the author has been able to test, the direction of fast axis has been parallel to the direction in which the et was extruded. This direction can be found by examining the sheet in a strong light, when the extrusion marks will be visible as a system of hair lines traversing the sheet.

The author has used three methods to determine the phase delay; the first of these also distinguishes between the fast and slow axes. With the first method, a Michelson interferometer is set up to show fairly narrowly spaced white light fringes. A strip of the material to be measured (for convenience cut with its edges parallel to the axes) is mounted under slight tension across an aperture in a metal plate, and placed in one of the interferometer beams. The white light fringes, where they pass across the strip, are then displaced. They are also distorted, because the strip is not of uniform thickness, though this is of no consequence in what follows. The displaced fringes are now viewed through Polaroid sheet, with its vibration direction parallel first to one and then to the other of the axes of the strip. It will be found that in one of these positions of the Polaroid the fringe displacement is more than in the other; in this position the vibration direction of the Polaroid is parallel to the slow axis of the strip. The difference of the displacements for the two positions of the Polaroid measures the phase delay; for example, if the material is to be suitable for the construction of quarter-wave plates, the difference between the two displacements must lie between $\frac{1}{8}$ and $\frac{3}{8}$ of a fringe.

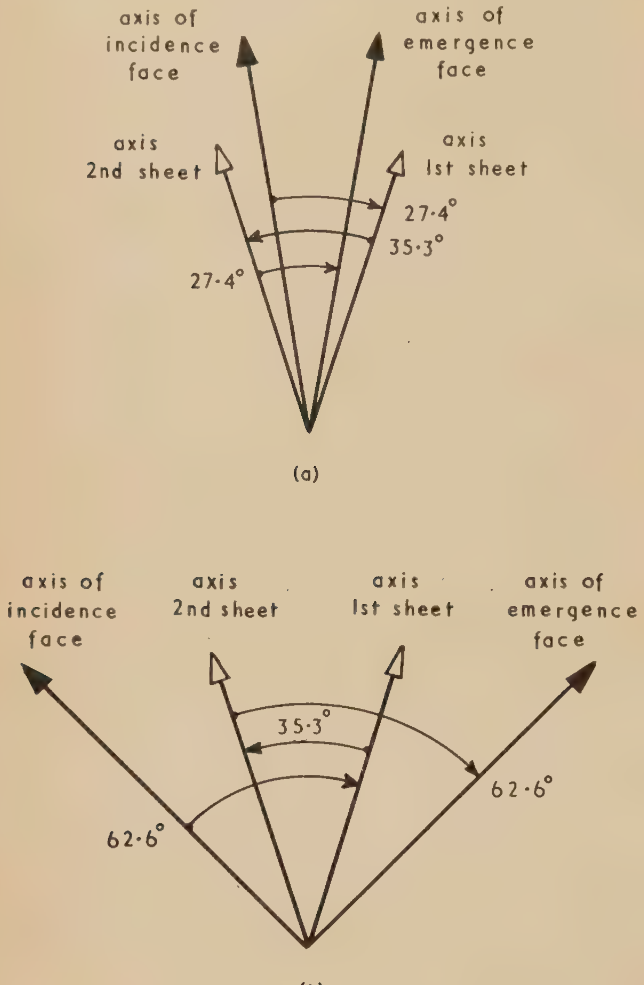
With the second method, a Babinet compensator is set up in the usual way to show fringes. These fringes may be close together, and may need to be viewed with a low-power microscope. With polarizer at $\pi/4$ to the axes of the compensator, and analyser and polarizer parallel, each bright fringe represents a phase delay of an integral multiple of 2π. If a sheet of the material is introduced into the beam with its axes parallel to those of the compensator, the fringes will be displaced; if the sheet is rotated through $\pi/2$ about the beam, the fringes will be displaced an equal amount in the opposite direction. In the one position the delay of the sheet is added to that of the compensator in one-half of the field, and subtracted from it in the other half. With the sheet rotated through $\pi/2$, the reverse holds. The displaced fringes may be brought back to their original position by the adjustment on the compensator and hence the delay measured in terms of fringes. This is as much as can be done if the nature of its axes is not marked on the compensator. If the fast and slow axes are marked on the compensator, it should be borne in mind that the fringe shift is away from that half of the field which has its fast axis parallel to that of the material.

The third method uses a quartz wedge. This is equivalent to one-half of the Babinet compensator, and the arrangement of polarizer and analyser is the same as for that method, but the fringes are usually much larger, are easily visible with unaided vision and the displacement produced when the sheet of material is laid over the wedge may be directly estimated. Unless the nature of its axes is marked on the wedge, it is again not possible to discriminate between the axes of the sheet; should they be marked, however, the displacement of the fringes will be towards the thin end of the wedge when the fast axes of the sheet and of the wedge are parallel.

Whichever method of measurement is used it is worth while, after a preliminary trial with a single thickness, to repeat the process with a multi-layer sample. After the preliminary check with white light, the final accurate measurement should be made with monochromatic light with which it is intended to use the plate.

Manipulation

Quarter-wave plate. Once the phase delay is known the actual construction of a plate presents little difficulty. The assembly is conveniently carried out on a sheet of paper pinned to a drawing-board and carrying a diagram showing the relations between the various axes as determined from expressions (8) to (10). It is important to bear in mind the sign of θ_1 (see figure). Next, a $3\frac{1}{4}$ by $3\frac{1}{4}$ in. lantern slide cover is put down with a diagonal parallel to the effective axis on the incidence face, so that in use the plate will be conveniently oriented with an edge parallel to the plane of polarization of the incident light. The first sheet is next placed on the cover glass, with its axis parallel to the direction marked on the paper. It should be large enough to overlap the glass everywhere by an inch or two, and after it is correctly placed it should be pinned down. To show the axis of a sheet clearly a long extrusion line is chosen and its ends marked with needle pricks; a line drawn through these with a ball-point pen or a grease pencil shows up well during the assembly. The second sheet is dealt with similarly to the first, and finally the second cover is added. A weight placed on the pile then holds it securely whilst a razor blade is used to trim off superfluous material. After lifting the pile carefully be held securely with bulldog clips while being bound. adhesive binding strip should be used, rather than gu strip, to prevent any danger of moisture penetrating the and changing their characteristics. To complete the ope the effective axes should be marked on the faces of the Plates so made have been in use for a period of nearl years without any change of characteristics. They are satisfactory for most purposes, though when used to f dark-field circular polariscope the field has a slightly m appearance due to small variations of the phase delay constituent sheets.(3)



The relationship between the axes of a composite double quarter-wave plate: (*a*) when the phase delay of a single sheet is +60°; (*b*) when the phase delay of a single sheet is +120°

(Note: $\phi = \theta + \theta_1 + \theta_2$.)

Half-wave plate. Two composite quarter-wave pla series, with the effective fast axis on the incidence face second plate parallel to the effective fast axis on the emer face of the first plate, form a half-wave plate with s properties to those of a composite quarter-wave plate. polarized light incident on such a plate with its pla polarization parallel to one of the axes of the incidenc will emerge as plane polarized light with its plane r through $(\phi_1 + \phi_2)$, where ϕ_1 and ϕ_2 are the angles th which the axes of each quarter-wave plate respectivel rotated. If the plane of polarization of the incident makes an angle $\pi/4$ with the axes of the incidence face the emergent beam will again be plane polarized, but with the plane rotated through $(\phi_1 + \phi_2 + \pi/2)$. If ϕ ϕ_2 are both arbitrary and both positive, a plate with characteristics is not of much practical interest. If $(\phi_1$ - is equal to $\pi/2$, the half-wave plate is apparently n though, in fact, the axes of the incidence and emergence interchange. In this case, however, if the plate is made four identical sheets, each sheet would itself be a qu wave plate so that the plate could have been much simply constructed from only two sheets. If $(\phi_1 +$ equal to π, the half-wave plate is truly normal. In this if the plate is made from four identical sheets, each has a delay of $2\pi/3$; a quarter-wave plate made from t these sheets has the interesting property [see part (figure] that since ϕ is equal to $\pi/2$, an incident beam polarized in the plane of one of the axes emerges wi plane rotated through $\pi/2$, so that in addition to its qu wave properties the plate very usefully performs the monest function of a half-wave plate.

On the other hand, a general solution which provi normal half-wave plate is obtained when $(\phi_1 + \phi_2)$ is For a plate made of four identical sheets this results particularly simple construction, because to give ϕ opposite sign to ϕ_1 it is necessary only to reverse the in which the sheets are stacked. The procedure for structing such a plate is thus very similar to that for a qu wave plate; the first and second sheets are placed as quarter-wave plate, the third sheet is then oriented the as the second sheet, and the fourth sheet as the first. resulting plate has its axes on the emergence face pa with those on the incidence face, and is in every resp normal half-wave plate.

Triple composite plates. From the previous parag follows the possibility of constructing plates of no behaviour from three sheets, if it can be arranged tha rotation of axes produced by the first two sheets is neutr by combination with the third. When three identical s are used a particularly simple solution results, the first third sheets being stacked with axes parallel, whilst the of the second sheet is inclined to them at an angle θ. axis of the first sheet is then inclined to the effective ax ombination at an angle θ_1, and using the notation of the ous paragraphs

$$\cos 2\theta = (\cos \frac{\delta}{2} \cos \delta - \cos \frac{\Delta}{2})/\sin \frac{\delta}{2} \sin \delta \qquad (13)$$

$$\cos 2\theta_1 = (\cos \frac{\delta}{2} - \cos \delta \cos \frac{\Delta}{2})/\sin \frac{\Delta}{2} \sin \delta \qquad (14)$$

$$\sin 2\theta_1 = -(\sin \frac{\delta}{2} \sin 2\theta)/\sin \frac{\Delta}{2} \qquad (15)$$

e method of assembly of such triple plates follows closely hat described for double plates, with the additional lification that it is now possible to make the first and rd components a single unit by taking a piece of the terial and folding it about an axis. The second component cut and inserted between the leaves of the unit so that its s makes an angle of θ with the line of the fold. The triple nbination can then be mounted between cover glasses, for nvenience with the fold making an angle θ_1 with one of edges. The resulting composite plate then behaves as a rmal simple plate of delay Δ, with its effective axes parallel the edges of the cover glass.

To assist the design and construction of composite wave tes according to these principles, a few tables have been calculated for the commoner requirements. All values are in degrees and in each case it is assumed that identical sheets are used. Each table covers the full range of permissible values of δ. Table 1 refers to double-sheet quarter-wave plates and is calculated from expressions (8) to (10); each column gives related values of δ, θ_1 or θ_2, and θ. Table 2 is calculated from expressions (13) to (15) and refers to triple-sheet quarter-wave plates. Since such combinations have the properties of simple plates the axes of the incidence and emergence faces are parallel, so that θ_1, which gives the orientation of the incidence face axes, gives also the orientation of the emergence face axes. Table 3 refers similarly to triple-sheet half-wave plates.

Table 1. *Values of θ and θ_1 calculated for composite double quarter-wave plates*

δ	45	50	60	70	80	90	100	110	120	130	135
θ_1 or θ_2	0	−16·5	−27·4	−34·3	−39·9	−45·0	−50·1	−55·7	−62·6	−73·5	−90·0
θ	0	22·6	35·3	41·2	44·1	45·0	44·1	41·2	35·3	22·6	0

) For negative values of δ add 90° to θ_1 or θ_2; θ remains unchanged.
) No distinction is made between a $\lambda/4$ and a $3\lambda/4$ plate.

Table 2. *Values of θ and θ_1 calculated for composite triple quarter-wave plates*

30	40	50	60	70	80	90	100	110	120	130	140	150
0	−14·4	−16·7	−16·6	−14·8	−11·3	0 or 90	+69·1	+60·0	+51·9	+43·3	+32·0	0
0	43·4	56·3	64·6	71·2	77·6	90 or 0	18·9	24·2	26·2	25·6	21·3	0

) For negative values of δ between 30° and 90° add 90° to θ_1; for negative values of δ between 90° and 150° subtract from θ_1; θ remains unchanged.
b) No distinction is made between a $\lambda/4$ and a $3\lambda/4$ plate.

Table 3. *Values of θ and θ_1 calculated for composite triple half-wave plates*

δ	60	70	80	90	100	110	120	130	140	150	160	170	180
θ_1	0	−14·7	−19·5	−22·5	−24·6	−26·2	−27·4	−28·3	−29·0	−29·4	−29·7	−29·9	−30·0
θ	0	29·3	38·9	45·0	49·3	52·4	54·7	56·5	57·9	58·8	59·5	59·9	60·0

a) The values are independent of the sign of δ.
b) For $\delta = \pm 180°$ the solution is independent of θ, with $\theta - \theta_1 = 0$ or 90°.

REFERENCES

(1) Tuzi, Z., and Oosima, H. *Sci. Papers Inst. Phys. Chem. Res. Tokyo*, **36**, pp. 72–81 (1939).

(2) Jessop, H. T., and Harris, F. C. *Photoelasticity*, pp. 115–116, 178–180 (London: Cleaver–Hume Press, Ltd., 1949).

(3) Straub, H. W. *Z. Techn. Phys.*, **21**, p. 154 (1940). A typical sheet with a mean delay of 0·261λ had a mean deviation from this value of 0·0093λ, whilst the maximum deviation was 0·020λ.

A high-pressure diffusion cloud chamber in a pulsed magnetic

By A. P. Batson, B.Sc., P. N. Cooper, B.Sc., Ph.D.,* and L. Riddiford, M.Sc., Ph.D., A.Inst.P.,
Department of Physics, University of Birmingham

[*Paper received* 26 *March*, 1956]

A description is given of an 18 in. diameter high-pressure diffusion cloud chamber constructed for use with the Birmingham proton synchrotron. The associated equipment to provide a pulsed magnetic field of 13 kG at each synchrotron pulse is discussed and an account of the operation of the apparatus is given.

A conventional cloud chamber is sensitive to ionizing radiation for only a short time, of the order of one-tenth of a second, after the adiabatic expansion. Further, especially for high-pressure chambers, the time interval between successive expansions is long. This makes such an apparatus uneconomic for a study of interactions with the gas in the chamber, when it is used with a high energy particle accelerator such as the Birmingham proton synchrotron, which produces a pulse of particles every few seconds. The diffusion cloud chamber is continuously sensitive to low levels of ionizing radiation, and so does not suffer from these limitations. Such a chamber was first operated in 1936 by Langsdorf,(1) and in 1950 accounts of chambers of simpler design were published.(2,3) The principle is as follows. The top of the chamber is maintained at room temperature, whilst the base is cooled to a very low temperature. Close to the top is a reservoir of a suitable liquid (usually methyl alcohol), which saturates the surrounding gas with vapour, and at some level in the chamber the temperature will be low enough for there to exist a sufficient degree of supersaturation to cause condensation on ions.

The possibility of using a diffusion cloud chamber for experiments with particle accelerators led to the development of the theory in some detail by Shutt.(4) Bevan(5) has shown that the theory is in accord with experiment. In 1951 Shutt and his collaborators succeeded in operating such a chamber at high gas pressures and with high repetition rates using a pulsed source of radiation.(6,7) Subsequently the same experimental group(8) described two chambers for experiments with the Brookhaven cosmotron, both operating at a hydrogen pressure of twenty atmospheres. One is a circular chamber for use in a magnetic field, the other a very large one which permits considerably more gas to be exposed to the beam of particles in use. The decision to construct a diffusion cloud chamber and magnet for use with the Birmingham synchrotron was taken early in 1953, and it was completed in the latter half of 1954. Equipment of a similar nature has been built at Chicago,(9) Harwell(10) and Liverpool.(11) A complete account of an installation of this kind has not been given. This paper describes the equipment constructed at Birmingham, which has been used to study proton–proton interactions at 650 MeV, as reported in a separate paper by two of the authors.(12)

THE CLOUD CHAMBER

The chamber is 18 in. in diameter, and is of the downward diffusion type. Fig. 1 shows its main features. The construction is in two parts, the lower cylindrical section being the effective part of the chamber, the upper conical section completing a convenient design. The cylinder and ports for illumination are formed from ¼ in. thick stainless steel sheet, this being sufficient to withstand the test pressure of th atmospheres. The relatively low thermal conduct stainless steel means that less heat is required to ma given temperature gradient in the wall. Furthermore chamber operates in a pulsed magnetic field, the use

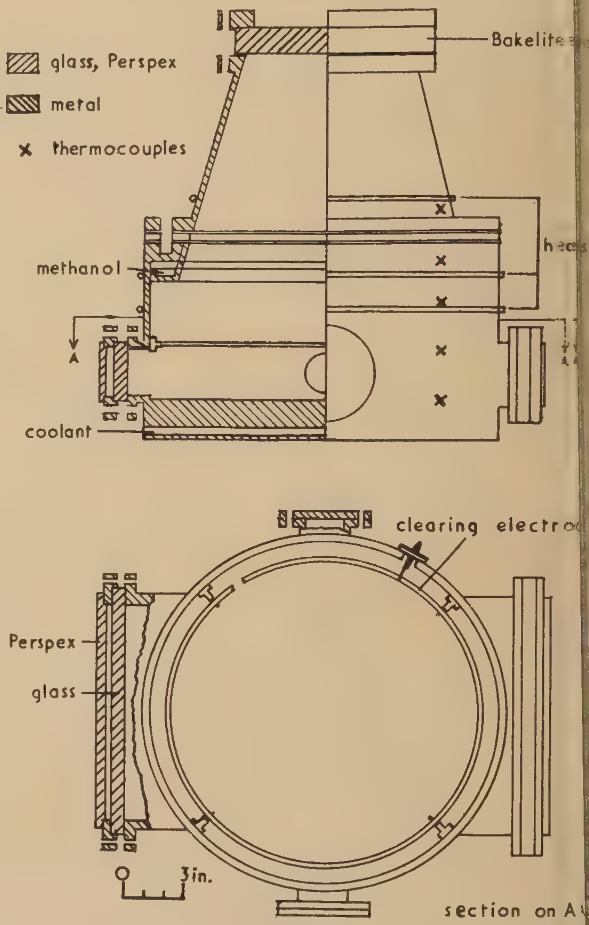


Fig. 1. The diffusion cloud chamber

non-magnetic material of high resistivity minimizes c tions in the field and the effects of eddy currents. The of the chamber is a 1½ in. thick mild steel disk. The mild steel improves the magnetic circuit substantially, r ing the power required to provide a given magnetic fiel thin-walled copper pipe of ½ in. outside diameter, i form of a spiral, is soft-soldered to the base. Comm methyl alcohol at a temperature of about −70° C is pu through this coil and maintains the temperature of the plate at about −60° C. The methyl alcohol is coold ng it through a heat exchanger consisting of a 21 ft h of ½ in. copper tubing, in the form of a spiral, placed equilibrium mixture of commercial methyl alcohol and carbon dioxide contained in a large drum. The coolant rculated by a 200 W Stuart-Turner centrifugal water p, modified for low temperature work by thermally ating the pumping chamber from the pump motor. has a capacity of several gallons per minute at the ure in question.

---

* Now at Associated Electrical Industries, Aldermaston, Berks.

ie tray from which the methanol vapour is supplied is nnular brass trough, 1 in. deep and about ¾ in. wide, slit ie point to minimize eddy currents. It has a capacity of t one litre, and so supplies sufficient vapour for several continuous operation without refilling. It may be ed, without releasing the high-pressure gas in the nber, from a reservoir of capacity about one litre which nnected to a drain in the chamber base. The tray is ly thermally connected to the top of the lower part of hamber, and is located so as not to obstruct the camera's of the sensitive region. A clearing field removes ions h would otherwise diffuse into the sensitive layer and ete the supply of vapour, and facilitates the removal of tracks between pulses of radiation. The electrode is in form of a (slit) ring of thick copper wire supported at points by ceramic insulators fixed to the wall of the nber. It is normally maintained at a negative potential 000 V, the high voltage being brought through the wall ie chamber on a K.L.G. metal-ceramic seal, soft-soldered small brass flange. The clearing field is removed about seconds before each pulse of particles enters the chamber, revent old cosmic ray tracks, made extremely diffuse by action of the field, from forming an unpleasant back-ind. Four seconds is sufficient time for these tracks to through the sensitive layer. The sides and base of the er section of the chamber are lined with black velveteen inimize the amount of scattered light. The velvet on the must be covered with a pool of methanol to prevent the from scattering obliquely incident light from the flash s into the camera. Recently the base velvet has been oved and a small quantity of the black dye Nigrosine (by I. Ltd.) dissolved in the methanol to provide a satisfactory tographic background. The upper part of the chamber is structed from ¼ in. mild steel sheet, and is thermally lated from the bottom part by a Bakelite spacer. This lation makes the performance essentially independent of temperature of the top, which may be kept quite warm revent a mist of methanol forming on the viewing window. large volume of the top part of the chamber should ensure ood flow of vapour to the centre of the sensitive region. tographs are taken through the 1¼ in. "armourplate" ing window* at the top of the cone. The two side dows are of ⅞ in. thick "armourplate." Since these dows are close to the cold base, to minimize frosting a thick sheet of Perspex is fitted in front of each, forming ouble window. The pressure seals are made by $\frac{3}{16}$ in. re soft rubber gaskets located in rectangular grooves, compressed by bolts sufficiently large to withstand the sure on the area concerned. Bakelite spacers between ges ensure a uniform distribution of stress on the glass st allowing adequate compression of the rubber. e washers are used as cushions between metal and glass aces.

The temperature gradient in the wall of the chamber is controlled by means of three electrical heaters encircling it in the positions shown in Fig. 1. Each heater consists of a 22 gauge Brightray wire (by Henry Wiggin and Co. Ltd.) on to which are threaded overlapping ceramic beads, the whole being enclosed in a $\frac{5}{16}$ in. outside diameter copper tube soft-soldered to the chamber wall. Five identical copper-constantan thermocouples, located as in Fig. 1, are used to measure the temperature distribution. The whole of the chamber, except for the windows, is lagged with a 1 in. thick layer of felt which assists in thermally insulating it from the magnet in which it is enclosed. Before filling with hydrogen, the chamber and reservoir are evacuated to an air pressure of less than 1 cm of mercury with a mechanical vacuum pump. This ensures that not more than 1% of the interactions observed at a pressure of 25 atm are with nucleons other than free protons.

Shutt[(4)] predicts a minimum temperature gradient in the sensitive volume of about 6·3° C/cm for satisfactory operation at this pressure. The best operating conditions with the present chamber are achieved with a temperature gradient of 6·8° C/cm in the sensitive depth and a much lower gradient between this and the vapour source, which is normally at about 23° C. If the vapour source temperature is increased above this value the sensitive depth increases a little, but there is a danger of general instability of the gas-vapour mixture. Gaps appear in the tracks which form mainly in regions of rather dense "rain." Satisfactory operation at a lower tray temperature of 10–15° C is possible if a velveteen

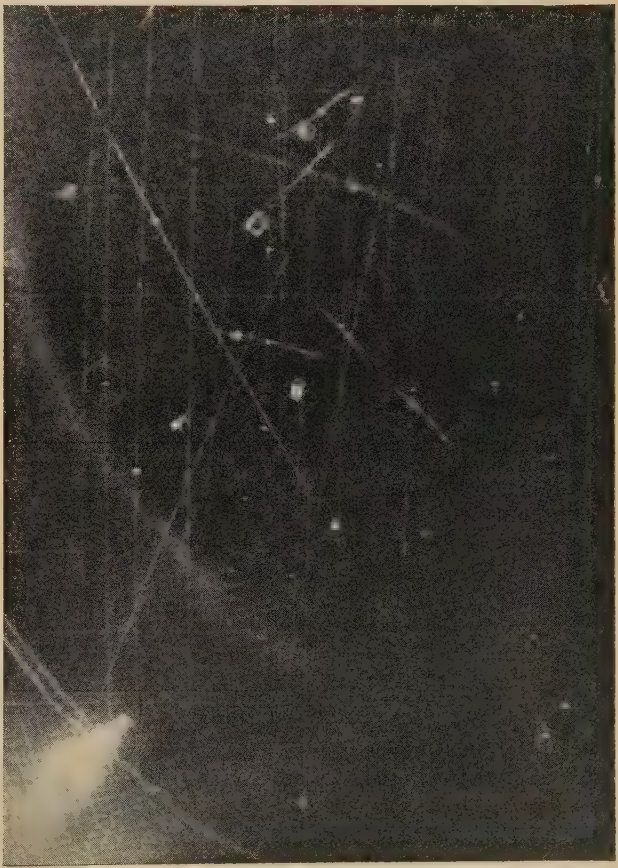


Fig. 2. Typical 650 MeV proton tracks. The reaction is of type $p + p \rightarrow n + p + \pi^{+}$

Because of the optical distortions resulting from this window, s now been replaced by a stainless steel plate on to which are l small windows of optically flat plate glass.

wick, dipping into the methanol tray and covering the entire surface of the conical section of the chamber, is added. However, the maximum safe operating temperature is correspondingly lower, and it is often not possible to maintain the tray temperature below 15° C under operating conditions because of the flow of heat into the chamber from the magnet coils and the eddy current heating in the chamber walls.

A sensitive depth of $2\frac{1}{2}$ in. is normally obtainable under ideal conditions, but the average sensitive depth throughout a full day's operation in conjunction with the synchrotron is usually only about 2 in. For an air filling at a pressure of three atmospheres a sensitive depth of $3\frac{1}{2}$ in. is readily obtainable. Normally the temperatures can be maintained close to the ideal ones throughout a long run by occasional adjustment of the heater settings. Considerable difficulty has been experienced at times due to quite large insensitive or less sensitive regions in which tracks do not form. Presumably these arose from the azimuthal asymmetry in the temperature gradient which must exist on account of the presence of the illumination windows. They have not been observed since thin sheets of Perspex were placed in the chamber in front of the windows to isolate the gas within the windows from that in the main part of the chamber. Tracks form within about 1 cm of the Perspex sheets. Normally excellent tracks are obtainable throughout the entire chamber. An example of such tracks is given in Fig. 2, which also shows a reaction of the type $p + p \rightarrow n + p + \pi^+$. The 650 MeV proton tracks are curved in the field of 13 000 G. Up to thirty high-energy tracks of minimum ionization density, plus the associated background, may be passed through the chamber at each synchrotron pulse without any apparent deterioration in performance. If the ionization level exceeds this, however, the appearance of the sensitive volume deteriorates because of the resultant depletion of the flux of vapour.

THE PHOTOGRAPHIC SYSTEM

The light source consists of two 400 J xenon-filled flash tubes (type LSD16 by Mullard Ltd.), one on each side of the chamber. Each tube is situated at the focus of a cylindrical lens $2\frac{1}{4}$ in. high, and connected to a condenser bank of capacity 132 μF at a potential of 2500 V. Since the tubes are in a quite strong pulsed magnetic field, to prevent breakages they are held in clamps of copper strip which grip them firmly but are themselves not quite rigid. The camera takes stereoscopic pairs of photographs through two Dalmac $f/3\cdot5$ lenses of focal length 2 in. (by J. H. Dallmeyer Ltd.) placed symmetrically one on each side of the axis of the cloud chamber. The angle between lenses as seen from the sensitive layer is about 10°. The aperture should not exceed $f/8$ to maintain an adequate depth of focus. Photographs are taken on 60 mm wide type 5G91 recording film (by Ilford Ltd.) and developed in X-ray developer type D19b (by Kodak Ltd.). The film is guided through the camera by rollers, and kept flat by pressure plates to which the condenser lenses required for satisfactory reprojection are attached. It is exposed in 100 ft lengths, each of which lasts about fifty minutes when pairs of photographs are taken at ten second intervals. The de-magnification factor is ten. The film is wound on after a photograph by a 24 W motor which drives a shaft connected to the wind-on spool in the camera. The motor is switched off after the film has moved the appropriate distance, by a cam-operated microswitch, the cam being driven by two sprocket wheels which engage in the film perforations. A significant interval of time must elapse between the instant of particle entry and the instant of photography. This time is kept as short as possible to minimize possible errors in momentum measureme to convective gas flow during the interval. For the exp described in Ref. 12 the time interval was 0·15 s, has now been reduced to 0·12 s as a result of impro in the illumination system. The pulse of particles fi synchrotron has a duration of several milliseconds on

For analysis of the photographs, the film is replace camera, and illuminated from a 250 W pre-set foc jection lamp mounted at the top of a reprojection tabl film may be accurately re-located in the camera if t phragm in front of the film is also the limiting stop reprojection system. The reprojection table is free t a distance of $3\frac{1}{2}$ in. in the vertical direction and 15 in direction of the horizontal line joining the axes of t camera lenses. It may be rotated freely about the axis, and also to angles of ±75° about a horizont Once the stereoscopic images have been made to c small electromagnets make it possible to lock the t any position, whence angles may be read on pro attached to it. Since all primary tracks move approx in the horizontal direction, the degrees of freed adequate for the investigation of almost any interac any part of the chamber. Curvatures are measured b parison with arcs very carefully drawn on stiff board track in question is alined at right angles to the hor axis of rotation of the table, and the apparent curva space measured after the two images have been b together. Only a dip angle correction is then neces obtain the true momentum in space.

THE MAGNET

The cloud chamber is placed in a strong magne which makes possible measurements of the mome particles whose tracks are photographed within it. general features of the seven ton magnet with the ch installed are shown in Fig. 3. The assembly is moun a stout trolley and Fig. 4 shows a photograph of the co equipment. The base of the chamber rests on a diameter pole, and is thermally insulated from it by thick ring of Bakelite and a packing of glass wool. T of the chamber fits into a conical hole machined in the member of the yoke, which may be removed to allow to the chamber should this be necessary. To minimize consumption and avoid overheating of the winding magnet is designed for pulsed operation, yoke and being constructed from $\frac{1}{2}$ in. thick steel plates. Care is in the construction to avoid loops in which eddy cu would circulate.

The coil boxes shown in Fig. 3 each contain six Individual coils consist of 108 turns of $\frac{3}{4} \times 0\cdot070$ in. c strip wound into a tight spiral, the insulation between being presspahn paper 0·010 in. thick. Insulation be coils is provided by $\frac{1}{2} \times \frac{5}{32}$ in. strips of Bakelite, twel interlayer. The top and bottom of each coil box is thick sheet of stainless steel, and the inner and outer are cut from sheet Bakelite. The greatest electrical s exist between the coils adjacent to the stainless steel and the earthed plates themselves. To avoid the poss of "tracking" following the accumulation of dirt and m in an air-cooled system, the insulation in these ar supplemented by the addition of $\frac{1}{16}$ in. thick Bakelite liners covering the stainless steel plates. The coil asse are made mechanically strong by pulling the plates to with stainless steel bolts, insulated with Bakelite s Forced air cooling is supplied to each box from a fan m

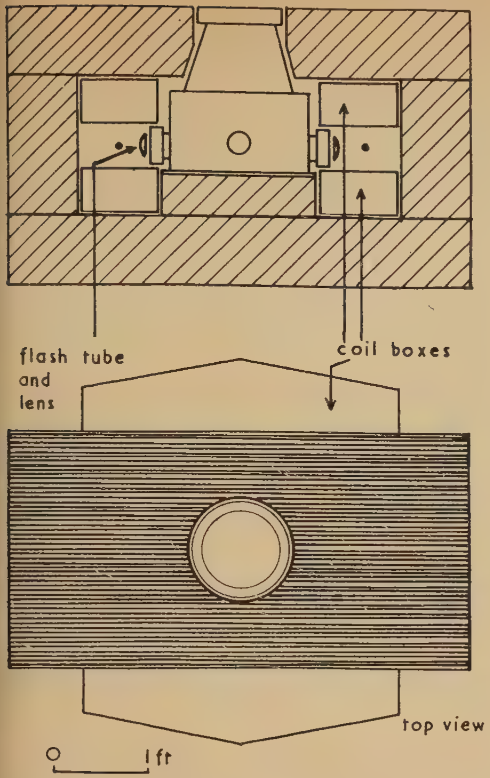

flash tube and lens
coil boxes
top view
0
1 ft

Fig. 3. Cloud chamber and magnet assembly

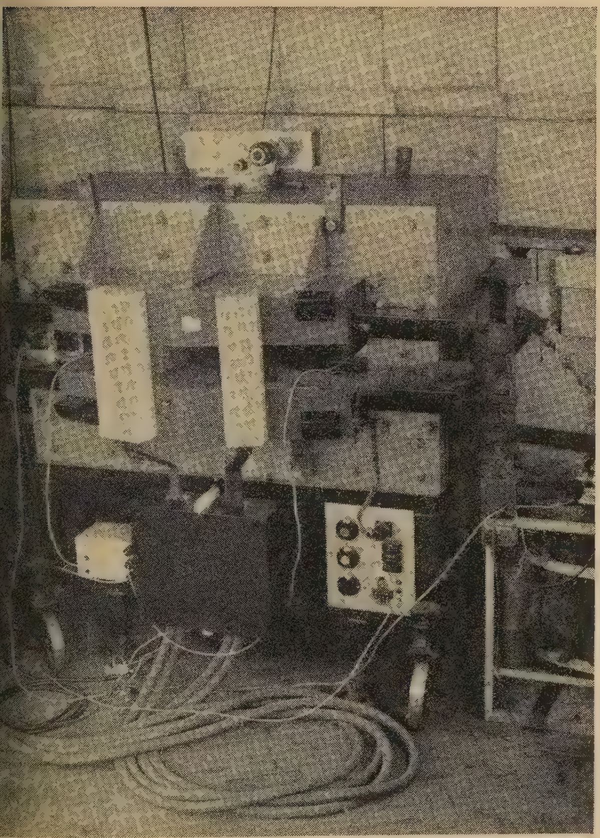


Fig. 4. General view of the equipment

on the magnet trolley. The fan is of the high speed axial flow type with a speed of 2900 rev/min, capable of delivering 1700 ft^3/min into a pressure head of $1\frac{1}{2}$ in. of water. Air circulates between the Bakelite spacers and is guided through the box by Bakelite baffles in such a way as to provide uniform cooling and a minimum resistance to the flow.

Each pair of coils is connected in series and the six pairs are excited in a series—parallel arrangement from a 500 kW

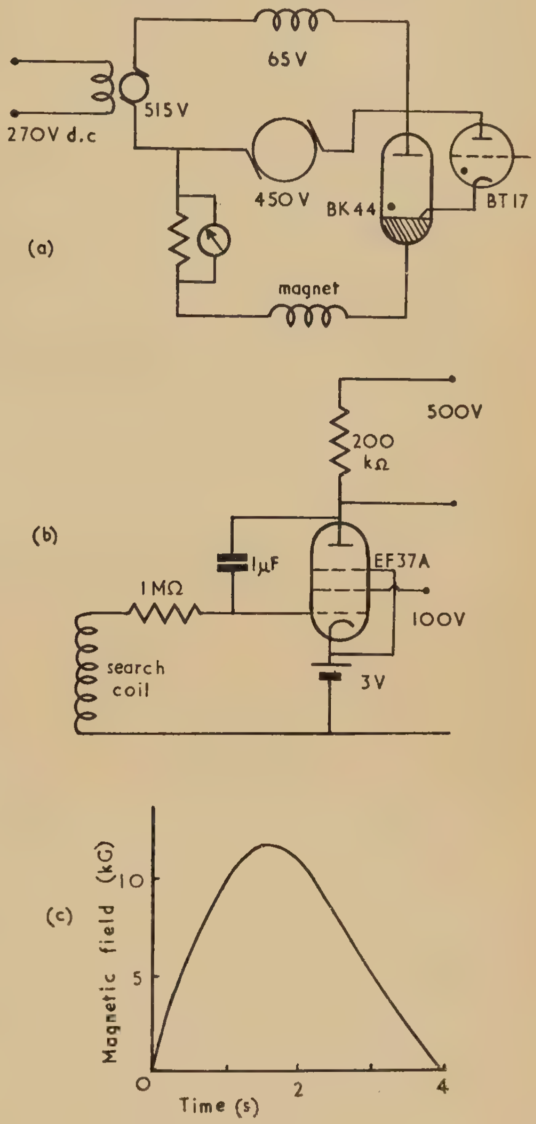

65 V
515 V
270 V d.c
450 V
BK 44
BT 17
(a)
magnet
500V
200 kΩ
(b)
1μF
EF37A
1 MΩ
100V
search coil
3V
(c)
Magnetic field (kG)
10
5
0
2
4
Time (s)

Fig. 5. (*a*) Magnet excitation system. (*b*) Miller integrator circuit. (*c*) Typical magnetic field pulse

d.c. generator, normally used to supply the magnet of the Nuffield Laboratory 60 in. cyclotron. The effective number of turns is 648, and in the present case the generator provides 400 V and 500 A peak to the cloud chamber magnet. The power circuit is drawn schematically in Fig. 5(*a*). To achieve a rapid build-up and shut-down time of the generator voltage, its field windings are excited from a 20 kW pilot exciter supplying about 515 V. A potential of about 65 V across the field windings is required to obtain an output of 450 V from the generator. The field windings and exciter are connected in series across the armature of the main generator. When the pilot exciter is switched on a potential of 515 V is applied to the field windings, resulting in a rapid rise in the armature potential to 450 V, when the potential across the field windings has decreased to the equilibrium value of 65 V. At this stage the current to the magnet is switched on by means of a water-cooled metal ignitron (type BK44 by British Thomson-Houston Co. Ltd.). This is done by what manufacturers call an "anode firing" circuit. A type BT17 mercury vapour thyratron (by British Thomson-Houston Co. Ltd.) is connected across the anode and the igniter of the ignitron so that its anode potential is supplied from the generator. When a positive potential is applied to the grid of the thyratron, the anode current of the thyratron triggers the ignitron, to which the current is transferred, the potential across it falling to such a value that the thyratron goes out. The current to the field windings of the exciter is reversed about one second after the main current has started. This causes a potential of −965 V to appear across the main field windings, forcing the output potential of the main generator to a negative value. The ignitron current reaches its maximum value of about 500 A in 1·3 seconds, and thereafter decreases, becoming zero after 4 seconds when the ignitron goes out, the excitation of the pilot exciter being removed some time before this. For the best accuracy in timing, this excitation is applied, reversed and broken by spring-loaded high-speed relays placed in the 270 V, 0·6 A d.c. side of the power supply.

For one pulse every ten seconds, the mean power dissipation in the coil is about 15 kW and the air emerging from the coil boxes has an equilibrium temperature of 60–65° C. Various safety devices are incorporated to disconnect the field supply to the exciter in the event of trouble. These comprise an overload relay operated from the shunt to the main current ammeter, a water switch in the ignitron cooling system, a thermostat attached to what should be the hottest place in the coil box, and a centrifugal switch on the fan.

The magnitude of the magnetic field has been measured under both steady and pulsed conditions. The steady-state measurements were made with search coils and a Grassot fluxmeter, and also by Mr. H. R. Shaylor using the proton resonance apparatus designed by him for use in the magnet of the 60 in. cyclotron. The two methods gave results which agree to within 1%. The pulsed field was observed by integrating the signal from a large search coil of area—turns $8 \cdot 31 \times 10^5$ turns. cm^2. The output potential from this coil is sufficiently large without amplification to make accurate measurements on an oscilloscope trace possible. Consequently a simple Miller integrator circuit as drawn in Fig. 5(*b*) was constructed, and traces showing magnetic field as a function of time recorded [Fig. 5(*c*)]. The linearity of the integrator and the sensitivity of the oscilloscope in both potential and time were carefully checked. The peak magnetic field measured by this means agreed to within 2% with that recorded for steady-state operation at the same current as the peak value recorded by the ammeter under pulsed conditions. Further, it was shown that the peak ammeter reading was equal to the peak current to within 1%. Thus the magnetic field measurements were consistent within themselves, and it is possible to use the peak ammeter reading as a measure of the magnetic field. The spatial variation of the field was measured under steady-state conditions by a difference coil method using a fluxmeter. The distribution depends quite strongly on the degree of excitation. At the current normally used (500 A) the extreme variation within the sensitive volume is ±6%, which is of the same order as that usually found for cloud chamber magnets of this type. The worst variations occur near the outer edge of the chamber. The mean field for 500 A is taken to be 13 000 G, and repeats from p pulse to within ±1%.

The timing sequence for cloud chamber operation r related to the synchrotron cycle. Synchrotron tim derived from a precision rotating condenser which c the frequency of the accelerating potential in this mach Light flashes from mirrors attached to this condenser a to regulate the speed of a synchronous motor, which a cam used to tune the radio-frequency power amplifie cloud chamber timing is derived mainly from a se microswitches operated by cams attached to a shaft w suitably geared to the shaft of the synchronous moto magnet timing is adjusted so that the field has its ma value when the pulse of high energy particles appears. may be simply done by observing the output fro integrator and the pulse of particles recorded by a scinti counter on a cathode-ray tube. The adjustment is not since the top of the magnetic field pulse is quite ro The cam-switches are also used to wind on the film camera between photographs, and to remove the clearin at the appropriate time, as described previously. Th tubes are triggered by a pulse from one of the mirrors at to the precision condenser. One of the cam switches op a selector switch and relays so that, if required, the chamber sequence and acceleration of the synchrotron occur only at each second, third or fourth synchrotron This makes satisfactory operation possible should the le background ionization associated with any beam be too to permit the use of the diffusion chamber each synch pulse.

ACKNOWLEDGEMENTS

We are grateful to Prof. P. B. Moon for his interest i work. The apparatus could not have been constructed out the skilful technical assistance of Mr. C. C. Barro Mr. R. H. Joines. During the past year Mr. B. Culwic made substantial contributions to its improvement. guidance of Dr. F. Aughtie in the design of the exc system was invaluable. The cost of the equipment was by the Department of Scientific and Industrial Resear whom two of us (A. P. B. and P. N. C.) are gratef maintenance grants.

REFERENCES

(1) Langsdorf, A. *Rev. Sci. Instrum.*, **10**, p. 91 (193
(2) Cowan, E. W. *Rev. Sci. Instrum.*, **21**, p. 991 (195
(3) Needels, T. S., and Nielson, C. E. *Rev. Sci. Ins* **21**, p. 976 (1950).
(4) Shutt, R. P. *Rev. Sci. Instrum.*, **22**, p. 730 (1951)
(5) Bevan, A. R. *J. Sci. Instrum.*, **31**, p. 45 (1953).
(6) Miller, D. H., Fowler, E. C., and Shutt, R. P. *Sci. Instrum.*, **22**, p. 480 (1951).
(7) Shutt, R. P., Fowler, E. C., Miller, D. H., T dike, A. M., and Fowler, W. B. *Phys. Rev* p. 1247 (1951).
(8) Fowler, W. B., Shutt, R. P., Thorndike, A. M. Whittemore, W. L. *Rev. Sci. Instrum.*, **25**, p (1954).
(9) Schluter, R. A., and Wright, S. C. *Rev. Sci. Ins* **26**, p. 1053 (1955).
(10) Snowden, M. *Progr. Nuclear Phys.*, **3**, p. 1 (1953).
(11) Alston, M. H., Crewe, A. V., and Evans, W. H. *Sci. Instrum.*, **25**, p. 547 (1954).
(12) Batson, A. P., and Riddiford, L. *Proc. Roy. So* To be published.
(13) Hibbard, L. U. *J. Sci. Instrum.*, **31**, p. 363 (1954).

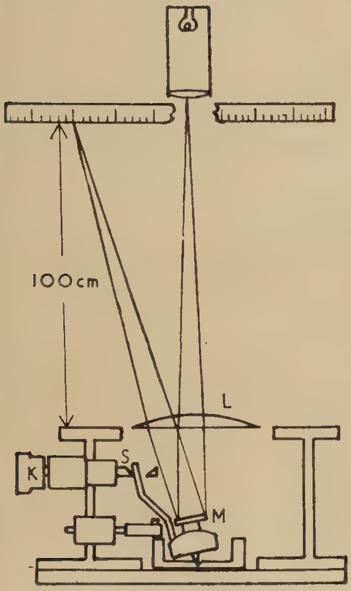
Calibration of the specimen tilt device of the EM-3 electron microscope

By J. A. Gard, B.Sc., A.R.I.C., Chemistry Department, University of Aberdeen

[*Paper received* 7 *May*, 1956]

An optical method is described for calibration of the specimen tilt device of the Metropolitan-Vickers type EM-3 electron microscope, for use in single-crystal electron diffraction.

ocedure has been described elsewhere* for improving ccuracy with which the radii of circular Laue zones in on-diffraction patterns may be measured. A series of ns is recorded from a crystal which is tilted through n angles by the device normally used for the preparation ereomicrographs. An optical method is described for calibration of the tilt device of the Metropolitan-rs type EM-3 instrument for this purpose.



ptical arrangement for the calibration of the specimen tilt device

he tilt mechanism has been described by Haine, Page Garfitt,† and was modified slightly to improve the racy. Knife-edges were filed on the stirrup *S* (see figure), hat the height of the point of contact with the bar on tilt block remained constant. Also, the grub-screw in operating knob *K* was replaced by a large-headed screw, minimizing errors in counting the clicks of the poppet, as the angular position of the knob could be located by touch. For the purpose of the calibration, the translation stage controls were adjusted to the centre of their normal travel. The specimen chamber was then removed from the instrument and bolted to a flat plate replacing the objective lens. The optical arrangement shown in the figure was similar to that of a mirror galvanometer. A small surface-silvered mirror *M* was attached to the tilt block by means of a blob of Plasticine. The collimated beam was focused by a metre lens *L* on to a scale, which was fixed exactly one metre from the lens, and was normal to the reflected beam when the specimen grid was horizontal. The tilt block was tilted to its limit in one direction, and the knob rotated in the reverse direction until the stirrup engaged the bar. The scale reading was then noted for every click of the poppet as the block tilted to its other limit, and again while tilting in the reverse direction. The knob was rotated back one click to eliminate backlash before taking each reading. The relation between the tangent of the angle of tilt and the number of clicks of the poppet was found to be linear within 1%, and to be almost independent of the horizontal position of the stage.

During operation of the device in the microscope, a small correction to the angle of tilt is necessary, as the specimen plane is a little below that of the tilt block fulcrum, and the image of the crystal must be centred before recording the diffraction pattern. The tilt block is, in effect, tilted about the crystal rather than about the mechanical fulcrum, thereby reducing the angle of tilt. The true angle of tilt ϕ is given by

$$\tan \phi = (1 - p) \tan \phi'$$

where p is the ratio of the specimen shift to the corresponding stirrup movement, and ϕ' is the angle of tilt derived from the optical calibration.

In an experiment to evaluate the correction p, the image shift was measured on a plate carrying two exposures recorded at low magnification, corresponding to a few clicks of the poppet device with the translation controls stationary. The stirrup movement was calculated from the pitch of the operating screw. Then

$$p = \text{shift of image}/(\text{magnification} \times \text{stirrup movement}).$$

In the instrument used for this work, the correction p was found to be almost exactly 3·0% over a wide range of specimens in the normal cartridges.

Gard, J. A. *Brit. J. Appl. Phys.* To be published.
Haine, M. E., Page, R. S., and Garfitt, R. G. *J. Appl.* ., **21**, p. 173 (1950).

A "hodoscoped" cosmic-ray recorder

By J. C. Barton, B.Sc., Ph.D., University College of the West Indies, Jamaica, B.W.I.

[*Paper first received* 15 *December*, 1955, *and in final form* 7 *February*, 1956]

A portable Geiger–Muller counter apparatus is described. It includes an eight-channel hodoscope and is designed for use at great depths. Simple transistor circuit techniques are used in conjunction with magnetic tape recording. A discussion is given of the operation of counters from a stabilized voltage supply for greatest possible battery life. The complete equipment consumes about 50 mW and will operate unattended from one set of batteries for longer than a month. The apparatus has been operated successfully in a coal mine at a depth of 1500 ft below the surface.

A previous paper(1) describes a portable cosmic-ray equipment which had been designed for making measurements of the total intensity of the cosmic radiation at great depths in the sea. However, the apparatus needed to be raised and lowered at times previously selected and the useful life of the batteries, when the apparatus was immersed in deep water at a few degrees Centigrade, was only three or four days. While designing a new version it was decided to include a simple hodoscope. It would thus be possible to record simultaneously the angular distribution of the radiation, the proportion of showers and the total intensity. This paper describes an apparatus which meets these requirements. The size of the complete recorder had to be the same as the first equipment and it has proved convenient to use exactly the same Perspex inner case containing a three-fold telescope with four counters in each bank; this enabled many of the details of the earlier apparatus to be retained in the new one. It is sufficient to hodoscope the counters in the top and bottom banks only. The method adopted consists of recording the eight channels on standard ¼ in. magnetic tape for economy of space. Transistor circuits are used to economize in the power consumed.

HIGH-VOLTAGE SUPPLY

The usual method of supplying the high voltage array of counters requires a relatively large current th the supply potentiometer to ensure that leakage c are not troublesome. The counter voltage supply c shown in Fig. 1 require two corona stabilizer tubes other respects have many advantages: the maximum v above or below earth potential is smaller; the whole p meter is at a low voltage so that the effect of any i resistance is reduced; the minimum current for the v stabilizer tubes increases with operating voltage so t dividing the total voltage in the correct ratio the c drawn from each supply may be the same. The total m current for both the −1000 V and the +400 V supp about 10 μA (individual corona tubes show some va in their minimum currents).

The remaining design problem is to choose values stabilizing resistances which give the maximum batt The arguments of Holton and Sharpe(2) are not very re to this problem as they were more concerned wit stabilization than with battery economy. The analys in the appendix has therefore been used, although it m

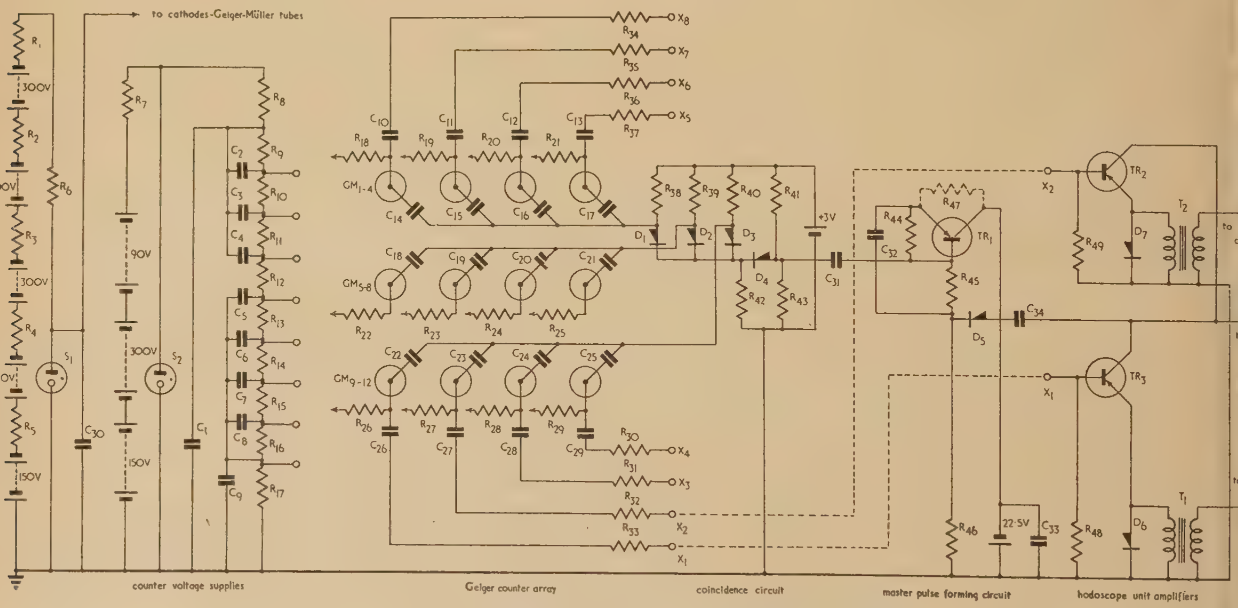

to cathodes-Geiger-Müller tubes
R1
300V
R2
300V
R6
R3
300V
R4
300V
S1
R5
150V
C30
R7
90V
300V
S2
150V
C1
R8
C2
R9
C3
R10
C4
R11
R12
C5
R13
C6
R14
C7
R15
C8
R16
C9
R17
R34
X8
R35
X7
R36
X6
R37
X5
C10
C11
C12
C13
R18
R19
R20
R21
GM1-4
C14
C15
C16
C17
C18
C19
C20
C21
GM5-8
R22
R23
R24
R25
C22
C23
C24
C25
GM9-12
R26
R27
R28
R29
C26
C27
C28
C29
R30
X4
R31
X3
R32
X2
R33
X1
R38
R39
R40
R41
+3V
D1
D2
D3
D4
R42
R43
C31
C32
R44
R47
TR1
R45
D5
C34
X2
TR2
T2
R49
D7
X1
TR3
R46
22·5V
C33
R48
D6
T1
counter voltage supplies
Geiger counter array
coincidence circuit
master pulse forming circuit
hodoscope unit amplifiers

Fig. 1. Circuit diagram of hodoscoped recorder

R_1–R_5 = 1·5 MΩ
R_6 = 2·2 MΩ
R_7, R_8 = 3·9 MΩ
R_9–R_{16} = 3·3 MΩ
R_{17} = 8·2 MΩ
R_{18}–R_{29} = 2·2 MΩ
R_{30}–R_{37} = 33 kΩ
R_{38}–R_{40} = 6·8 kΩ
R_{41} = 47 kΩ
R_{42}, R_{43} = 68 kΩ

R_{44} = 33 kΩ
R_{45} = 4·7 kΩ
R_{46} = 2·2 kΩ
R_{47} = 3·3 MΩ
R_{48}, R_{49}, . . . = 1 MΩ

C_1–C_9 = 0·01 μF
C_{10}–C_{13} = 0·001 μF
C_{14}–C_{25} = 300 pF

C_{26}–C_{29} = 0·001 μF
C_{30} = 460 pF
C_{31} = 0·002 μF
C_{32} = 0·1 μF
C_{33} = 8 μF
C_{34} = 2 μF

T_1, T_2, . . . = 12·5 : 1
Fortiphone size T

S_1 = 1000 V corona stabilizer
S_2 = 400 V corona stabilizer

D_1–D_4 = GEX 45/1
D_5 = GEX 34
D_6, D_7, . . . = OA 71

TR_1 = OC 51
TR_2, TR_3, . . . = OC 71

itted that this over-simplifies the factors on which ery life depends. This predicts that an array of type batteries (by Ever Ready Co. Ltd.) should last for it four months at room temperature. It is not yet pos- to say whether this life will always be obtained in tice, but one set of batteries has already lasted for nearly e months. At 0° C battery performance is worse by a or of about two so that the life will then be about two ths.

HODOSCOPE CIRCUIT

his circuit has been designed so that no power is dissi- d in any of the eight channels except when an event is ng recorded. This is realized by arranging that a three- l coincident event triggers a master circuit which switches the voltage supply to the channel amplifiers. If the nter of any channel has simultaneously been discharged amplified pulse is fed to the same channel of the magnetic d.

he circuit is shown in Fig. 1. The master pulse forming uit uses a trigger circuit of the type first described by ch and Ungvary(3) but modified to provide a negative put pulse. The triggering sensitivity of this circuit is reased by the use of the two resistances R_{44} and R_{47}, ich is essentially a variation of the method given by llingstad and others(4) and Harris.(5) The value chosen R_{47} depends on the characteristics of the particular nsistor; in some cases it may be omitted. The crystal de in series with the output prevents triggering of the cuit by pulses fed back from the hodoscope units. With a ½ V battery the output pulse is about 12 V and can supply mA with only a small drop in amplitude. The dead-time the circuit is rather long, 10 ms, but this is unimportant the present application where counting rates are extremely v.

The hodoscope unit circuits each consist of a junction nsistor operated in an "earthed collector" circuit. lthough the collector is not in fact earthed but receives the aster pulse, the latter should be regarded as an h.t. voltage ich is only switched on for a short time.) This arrangement chosen because it provides a voltage gain of unity, which is fficient as both master and counters pulses have a maximum plitude of about 10 V, and current gain of $1/(1-\alpha)$ e ref. (6)]. Using transistors type OC71, for which $= 0{\cdot}979$, the input impedance is 0·24 MΩ for a load of 00 Ω. The shape of the current pulses in the recording ads is determined by the characteristics of the Geiger unters; the effective impedance of the magnetic recording ads for these pulses is about 30 Ω. This determines the cessary turns ratio of the output transformers, which are de by rewinding Fortiphone size T sub-miniature trans- rmers. The crystal diodes which shunt the transformer maries prevent any overshooting of the pulses.

MAGNETIC-TAPE RECORDING

It has been necessary to develop special techniques to able eight tracks to be recorded on standard ¼ in. magnetic e. Technical details of the head construction and of the of a "mutual deductance" to reduce interference between annels will be given in a later paper by Barton.(7) The in the magnetic heads is only 0·01 mm and, even ugh the fringing effect at the gap is large, the magnetized ion on the tape is less than 0·1 mm. This means that nts occurring at random may have an average separation of only 5 mm for a 2% probability of events overlapping. As the apparatus is only required to function at depths below sea level of more than 1000 metres of water, where the total number of events is always less than four an hour, a tape advance of only 2 cm/h is sufficient.

The simplest way of driving the tape at this very slow rate is to use a clock movement. By mounting the take-up spool directly on the hour spindle the necessary spool diameter is 3 in. The total thickness of standard magnetic tape is 0·0021 in. so that a ⅛ in. deep groove on the drum can take a month's supply of tape. There will, of course, be a small variation of tape speed between the beginning and end of the tape, but this effect can easily be calculated.

It has not been possible to find an ordinary spring-driven clock which was sufficiently small and would operate for 28 days on one winding. Instead a Reform electrically wound movement, supplied by Southern Watch and Clock Supplies Ltd., has been used and found ideally suited to this requirement. It operates from 4·5 V and even small size dry batteries (Ever Ready type U8) are sufficient for many months' operation. It can pull the tape at the rate of 2 cm/h with a force of about 1 oz wt; the frictional force due to the spring-loaded pad pressing the tape against the head can be less than this while still maintaining good contact between the tape and lead. The movement of the tape was observed under a low-power microscope and showed no signs of jerkiness.

COMPLETE EQUIPMENT

The lay-out of the various parts of the circuit in the Perspex case is shown in Fig. 2. Sixty of the type B 123 batteries are in the same positions as in the earlier apparatus(1) but three more are now included in one of the hemispherical ends. This end has been redesigned so that the plugs which tap on to the high-voltage potentiometer are locked in position when the end is attached to the main case. The other end contains only the magnetic tape "deck" which is mounted on rubber blocks. All the transistor circuits occupy very little space; the unit amplifiers on each channel require a volume of about 1 in.^{3}

PERFORMANCE

In an ideal hodoscope there is no recorded signal on any channel when there is no coincidence, and no signal on those channels where the counters have not been discharged when there is a coincidence. The circuit described is ideal in the first respect but not in the second. However, the current in a magnetic head due to a spurious pulse is not more than one quarter of that due to a true pulse. Since the recording characteristic of the magnetic tape is extremely non-linear the ratio for recorded pulses is very much less, so that these spurious pulses give no trouble in practice.

The master pulse forming circuit is not critically dependent on battery voltage, but the output pulse becomes smaller as the battery discharges; operation down to 18 V is certainly satisfactory. Using two 22½ V units, from a type B 126 battery, in parallel this permits operation for several weeks at 20° C, depending on the minimum collector current of the particular type OC51 transistor; 1 mA is a typical value. For longer periods of operation, particularly at lower temperatures, an array of Mallory type 1R batteries may be used instead. All the other batteries in the apparatus are sufficient for at least two months' continuous operation.

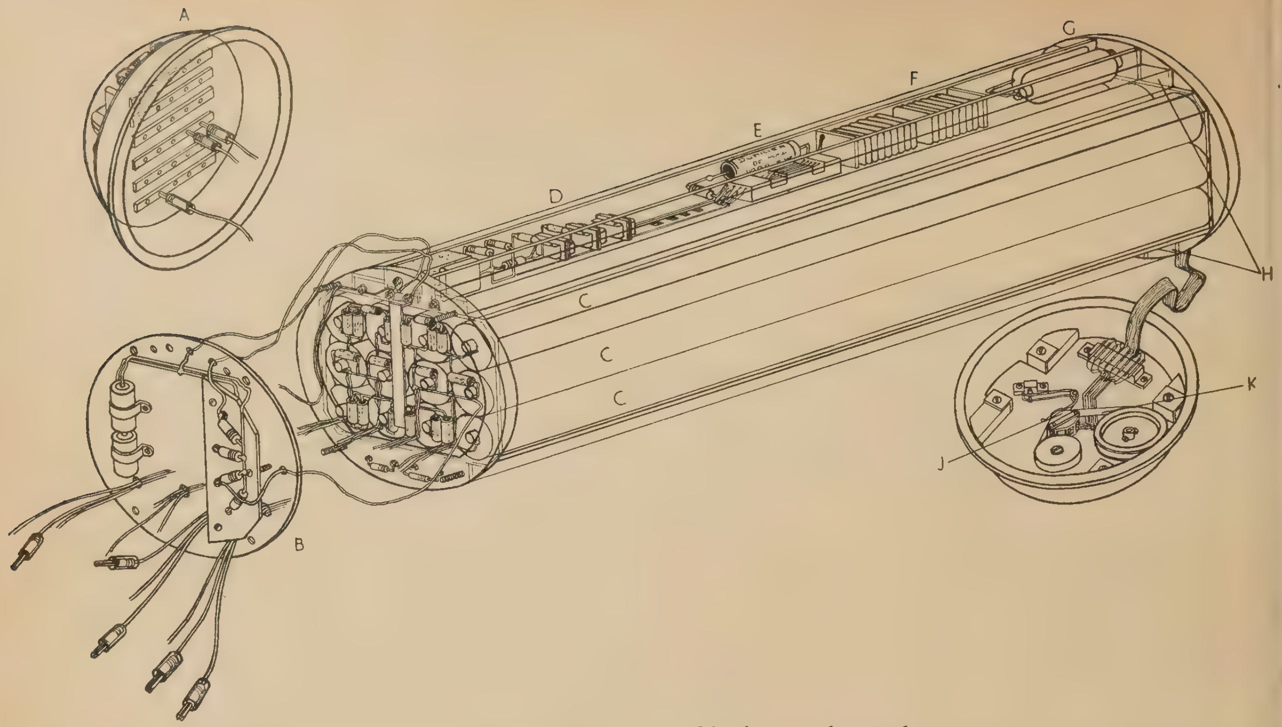


Fig. 2. General arrangement of hodoscoped recorder

A, high-tension distribution panel; *B*, coincidence circuit; *C*, *G–M* counters; *D*, transistor amplifier circuits with miniature transformers; *E*, mutual deductance; *F*, low-tension batteries; *G*, corona stabilizer; *H*, high-tension battery compartments; *J*, recording magnetic head; *K*, ¼ in. magnetic tape.

Transistor circuits are liable to be very sensitive to temperature changes, but those described have been tested over the range 0 to 30° C and found satisfactory. The only transistor failure occurred while the point contact circuit was being tested with an improperly earthed oscilloscope.

It is not possible to test the apparatus in a really satisfactory manner at sea level as the rate of events is far too great. In the summer of 1955 there was an opportunity to test the equipment in a coal mine at a depth of 1500 ft. Readings were obtained over a period of several weeks and these showed that the apparatus was functioning in the manner intended.

The total power consumed by the whole equipment is extremely small, about 80 mW when the batteries are new falling to 30 mW at the ends of their lives. It seems likely that still lower figures will be possible once sufficient experience has been gained about the dangers from leakage currents. It should soon be feasible to build a hodoscoped counter apparatus which will function unattended for a time limited only by the finite life of Geiger counters which are operated without quenching circuits. An incidental advantage which results from operating at very low power is that component failures are extremely rare.

The performance of this equipment may be compared with that of the portable hodoscope described by Linsley$^{(8)}$ in which the records were made on electrically sensitive paper. The power consumption of this apparatus was quoted as 300 mW *per channel*, which was partly due to the use of valves instead of transistors, and partly because an energy of 5000 ergs was necessary to give a visible mark on the paper; only 20 ergs is required to record a signal on magnetic tape. Linsley's apparatus used the type of recording paper which can only be used damp and the Teledeldos type of paper requires still higher power. The thickness of recording paper is about the same as that of magnetic tape but th latter can record about thirty times as much information pe unit area. The only advantage of recording on sensitiv paper is that the records can be studied without an additional equipment.

The method which has been used to analyse the magneti tape records will be described in a later paper.$^{(7)}$

ACKNOWLEDGEMENTS

The programme of measuring cosmic rays at great depth in the sea was initiated by a grant from the University o London Central Research Fund. I am greatly indebted t Mr. Tanfield and other officials of the National Coal Boar and to the Manager and men of Norton Hill Colliery i Somerset; their enthusiastic co-operation did much to ensur the success of the underground tests.

REFERENCES

(1) Barton, J. C. *J. Sci. Instrum.*, **32**, p. 226 (1955).

(2) Holton, P., and Sharpe, J. *Electronic Engn*, **25**, p. 6 (1953).

(3) Reich, H. J., and Ungvary, R. L. *Rev. Sci. Instrum.* **40**, p. 586 (1949).

(4) Follingstad, N. G., Shive, J. N., and Yaeger, R. E *Proc. Inst. Radio Engrs*, **40**, p. 1573 (1952).

(5) Harris, J. R. *Proc. Inst. Radio Engrs*, **40**, p. 1597 (1952)

(6) Shea, R. F. *Principles of Transistor Circuits*, p. 6 (New York: John Wiley and Sons Inc., 1953).

(7) Barton, J. C. *J. Sci. Instrum.* To be published.

(8) Linsley, J. *Rev. Sci. Instrum.*, **24**, p. 181 (1953).

APPENDIX

Design of corona stabilizer circuits for maximum battery life

Consider the circuit shown in Fig. 3 where we wish to etermine the value of R which gives the longest battery life. he initial battery voltage V should obviously be as high as ossible; it is limited only by the space available.

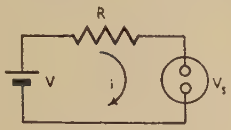


Fig. 3. Equivalent circuit of high-voltage supplies

ut $V_1 = \beta V_s$ where $\beta = 1{\cdot}35$ for this particular apparatus. lways $V - Ri = V_s$

$$\text{Initial current } i_1 = \frac{V_1 - V_s}{R} = \frac{(\beta - 1)V_s}{R}.$$

The final current i_2 is also fixed; 10 μA in this case.

Final battery voltage $V_2 = V_s + Ri_2$.

Provided the battery is not discharged too quickly we may ssume that the time taken for the battery voltage to decrease y dV varies inversely as the current.

Total life

$$T = \int_{t_1}^{t_2} dt = -k \int_{V_1}^{V_2} \frac{dV}{i} = kR \ln \frac{(\beta - 1)V_s}{Ri_2}$$

For this to have a maximum we find $R = (\beta - 1)V_s/i_2 e$ whence $R = 0{\cdot}35\ V_s/10\,e = 0{\cdot}013\ V_s$ in MΩ.

The resistance placed in series with the battery is chosen to have a value rather less than this, partly because the internal resistance of the batteries must be added and partly because there is a more rapid drop of voltage during the first few days' operation of the batteries.

We have also that the maximum life is $k(\beta - 1)V_s/i_2 e$.

We have measured the rate of decrease of voltage for a type B 123 battery and find that it is about $\frac{1}{3}$% per day for a discharge current of 40 μA at 20° C. This is an average figure which includes the initial rapid fall of voltage.

From this result we find that, for an initial voltage of βV_s, $k = 12000/\beta V_s$ μA days per volt, which gives $T = 115$ days.

This calculation is based on one particular size of battery. The use of larger batteries is prevented by lack of space and the smaller batteries available have such a poor value of k that this outweighs any possible improvement due to an increase in β.

Demagnetization of magnets due to contact with ferromagnetic bodies

By M. McCaig, Ph.D., F.Inst.P., Permanent Magnet Association, Central Research Laboratory, Sheffield 1

[*Paper received* 23 *April*, 1956]

The circumstances in which permanent magnets are partially demagnetized by repeated contacts with ferromagnetic bodies have been investigated. If a bar magnet is placed a few times on a block of mild steel and removed by a sliding motion parallel to its length, a loss of magnetization of the order 40% may occur. Over 3 mm thickness of protective material is necessary to keep the losses below 1%.

many scientific instruments permanent magnets are incor- orated, and the accuracy of the instrument depends on the ability of the magnet. Modern permanent magnets can be ade sufficiently stable to withstand the vibrations, stray agnetic fields and fluctuations in temperature likely to be et in normal use. Variations in the strength of an instrument magnet may be less important than many other factors ffecting the accuracy.

Contact with ferromagnetic bodies is a hazard to which a agnet may be exposed: e.g. a screwdriver might be used in ssembling or adjusting an instrument. Although it is well nown that such contact is injurious, there is little knowledge f the extent of the damage which a magnet may receive and e circumstances in which it may occur.

To investigate all the different shapes and varieties of agnets and all the ferromagnetic objects with which they ight come in contact would be neither possible nor worth- hile. These experiments are therefore confined to three bars described in Table 1, and the ferromagnetic body with which they made contact was a block of mild steel with dimensions larger than the length of any of the bars. It is hoped that the results will indicate the extent of the demagnetization possible, the circumstances in which it is most likely to occur and the precautions which should be taken in order that it may be avoided.

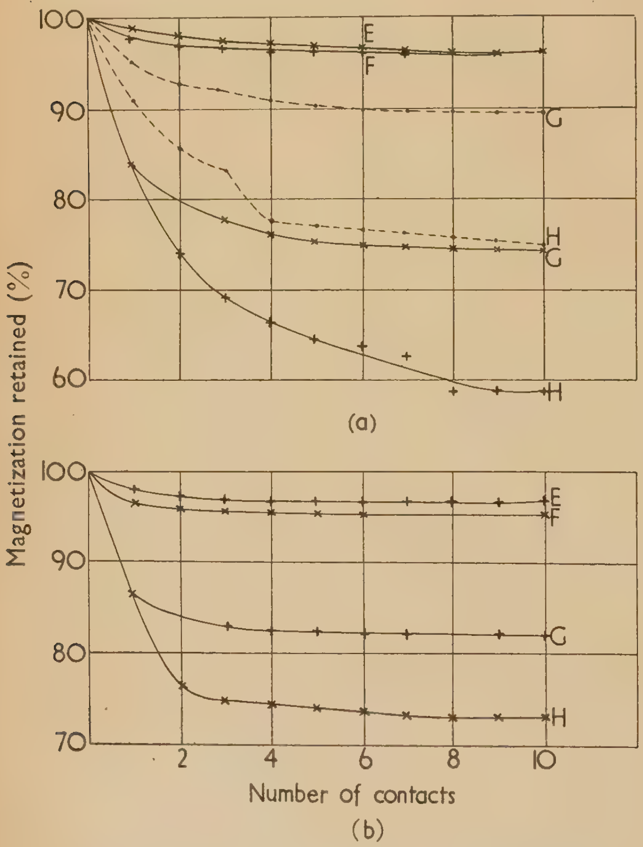
Table 1. *Properties and dimensions of magnets*

No.	*Material*	*Dimensions (cm)*	*Remanence kG*	*Coercivity (oersted)*	*$(BH)_{max}$ (MG oersted)*	*B/H at $(BH)_{max}$*	*B/H at working point*
1	Alcomax III	$5{\cdot}67 \times 1{\cdot}19 \times 1{\cdot}6$	12·4	655	5·13	18·6	17·8
2	Alcomax III	$3{\cdot}9 \times 0{\cdot}565 \times 0{\cdot}435$	13·0	645	5·39	19·2	44·8
3	Alnico	$5{\cdot}08 \times 1{\cdot}91 \times 1{\cdot}11$	7·5	545	1·63	13·3	13·3

A number of standard procedures of making and breaking contact between the magnet and mild steel block were then devised. The magnet was re-magnetized before each sequence of tests.

- *A*, touch one pole (end face) of magnet on to block and pull off at right angles to surface of block. Repeat up to ten times using the same end of magnet each time.
- *B*, as *A* but use each end of magnet alternately.
- *C*, as *A* but slide end face off block.
- *D*, as *B* but slide end face off block.
- *E*, place one side face of magnet on block and pull off at right angles to block. Repeat up to ten times using the same face of the magnet each time.
- *F*, as *E* but use each of the four side faces in turn.
- *G*, as *E* but remove magnet from block by sliding the side face off the block with a movement parallel to the axis of magnetization.
- *H*, as *G* but use each of the four side faces in turn.

The flux at the centre of the bars was measured by means of a search coil and ballistic galvanometer. With all three bars the loss of magnetization was small for any of the procedures *A*, *B*, *C*, *D* involving only end faces of the bars.



Magnetization retained after contact of magnets with iron. (*a*) Alcomax III: full lines, bar No. 1; broken lines, bar No. 2. (*b*) Alnico, bar No. 3. Letters indicate method of making and breaking contact as described in text

Under these conditions the greatest loss after ten conta was 1·2%; usually it was much less than 1%, and accuracy of the experiments is insufficient to permit generalizations about the different procedures. The los are very much greater for any of the procedures in which side of the magnet is placed on the mild steel block, as be seen from the figure.

This figure shows that losses exceeding 40% may occ After several contacts demagnetization is understanda greater if all four sides of the bar are touched in turn than the same side is touched each time. The largest losses occur with the Alcomax magnet No. 1 which has a smaller ratio length to area than No. 2. Qualitatively this observat may be explained on the grounds that the working point this magnet is close to the steep part of the demagnetizati curve. The figure also shows that the demagnetization greatest when the magnet is separated from the block by sliding motion. Separate experiments have indicated th the damage occurs chiefly when the magnet crosses the ec of the block with a motion parallel to the axis of the mag Sliding the magnet about on the block without crossi the edge, or even crossing the edge with a motion at rig angles to the length of the magnet have comparatively lit effect.

A very relevant question is what thickness of protect covering is necessary to reduce these losses by a given amou For this investigation the shorter Alcomax bar, working ne its $(BH)_{max}$ point, was used. Procedure *H*, sliding differe side surfaces of the bar in turn over the edge of the bloc was employed. Table 2 shows the percentage of magnetiz tion remaining after the tenth contact with different thic nesses of material placed between the magnet and block.

Table 2. *Effect of various thicknesses of protective materi*

Magnetization remaining (%)	61	67	68	84	87·5	95	9
Thickness of protection (mm)	0	0·1	0·2	0·6	0·8	1·48	3

Two other experiments may be mentioned as they ga rather unexpected results. Alcomax magnet No. 1 and second similar magnet were used. In the first experimen they were pressed together with like poles opposite and pulle apart. After ten contacts using all four faces of each magn their average flux had fallen to 76% of its original value. I the second experiment they were placed together with unlik poles opposite and were slid apart with a motion parallel t their length (the easiest way of separating them). This motio did, of course, bring one pair of like poles together. Agai after ten contacts using all four faces of each magnet, th magnetization had fallen to 42·5% of its initial value. Th treatment was the most drastic one of all tried. However, will be seen that the previous experiment of bringing bot pairs of like poles together was less harmful than sliding off mild steel block. The lesson is that a pair of bar magnet may be used to produce a mutual repulsion fairly safely The demagnetization often found in pairs of demonstratio magnets is due rather to the temptation they usually presen for various persons to play with them.

ACKNOWLEDGEMENTS

I thank the Permanent Magnet Association for permissio to publish this paper.

A precision electrode-less conductance cell for use at audio-frequencies

y S. R. Gupta, M.Sc., D.Phil., and G. J. Hills, Ph.D., Imperial College of Science and Technology, London, S.W.7

[*Paper first received* 23 *March, and in final form* 30 *April*, 1956]

The design and performance of a transformer bridge for the measurement of the electrolytic conductivity of concentrated aqueous solutions is described. It operates at audio-frequencies and does not involve the use of electrodes. With moderately and highly conducting solutions the reproducibility of the measurements is better than 0·02%.

arious ways of measuring the conductivity of solutions have een described which do not involve the insertion of electrodes s such into the solution. All of them use alternating current f high frequency and the solution is introduced electrically nto the circuits by electrodes placed on the outside of a treous container or by means of a surrounding coil.(1,2)

A simpler way of avoiding electrodes altogether and one hich does not employ high frequencies is the use of a trans- ormer bridge. The coupling between the two toroidal ansformers is provided by a closed loop which threads both ils, the loop in this case consisting of the solution, the nductivity of which is required, placed in a suitable non- nducting container. The coupling depends directly upon e conductivity of the loop and hence upon the conductivity f the solution.

This conductance can be readily determined by comparing with a standard conductance of known value. If this is oped through both transformers, in phase opposition in e voltage-transformer, then the bridge is balanced when ere is zero flux in this transformer as detected by auxiliary indings.

In the bridge used in the present work which was designed r the precise measurement of high conductivities (0·1–00 millimhos), the standard conductance was not composed f precision decade resistors but of three high quality standard sistors, the contributions of which could be varied by eans of selective tappings of the windings of the current ansformer. The arrangement used is shown in Fig. 1. The ores of both toroidal transformers were of Mumetal. They ere imbedded in an epoxide-resin, shielded from one another nd mounted as shown in Fig. 2. The glass loop was constructed *in situ* and the transformers-cell assembly was nmersed in an oil-bath, the temperature of which could be ontrolled to better than ±0·01° C.

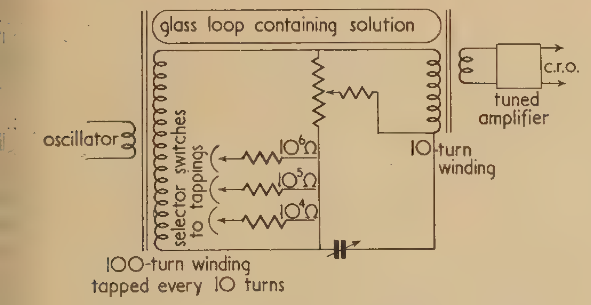

glass loop containing solution
c.r.o.
tuned amplifier
oscillator
selector switches to tappings
$10^6\Omega$
$10^5\Omega$
$10^4\Omega$
10-turn winding
100-turn winding tapped every 10 turns

Fig. 1. The transformer bridge arrangement

The conductance of the cell depends upon its geometry. he cell constant could be calculated for a tube of known olume and uniform cross-section without the uncertainties hich occur in the corresponding calculations for metal-in-glass conductivity cells. However, it was convenient to calibrate the apparatus using the usual conductance standards,(3) 0·1 and 1 demal potassium chloride solution.

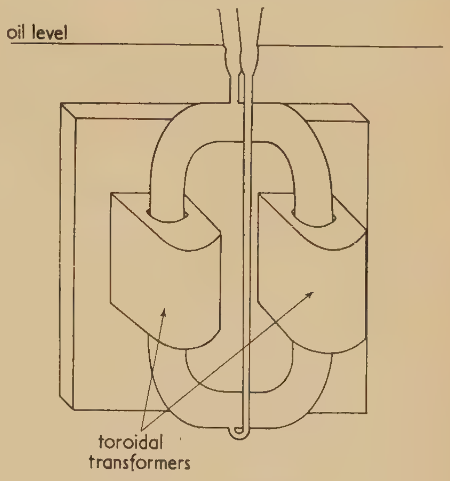


Fig. 2. The conductance cell

The reproducibility of the cell constant using these two standards is shown in Table 1.

Table 1. *Cell constants of two glass loops at 25° C*

	κ_{KCl}/*observed conductance* 0·1 demal KCl	1 demal KCl
Cell 1	16·535 ± 0·020	16·525 ± 0·005
Cell 2	38·742 ± 0·020	38·722 ± 0·005

In Table 2 equivalent conductances of potassium bromide and ammonium chloride are compared with the best data available from the literature. Apart from one unexplained deviation marked with an asterisk, the agreement is good

Table 2. *Equivalent conductances of potassium bromide and ammonium chloride at 25° C*

Concentration (mol l^{-1})	Λ_{KBr} (Ω^{-1} cm^2 mol^{-1}) *this work*	*Jones and Bickford*(4)	Λ_{NH_4Cl} (Ω^{-1} cm^2 mol^{-1}) *this work*	*Wishaw and Stokes*(5)
0·1	131·11	131·19	—	—
0·2	126·44	126·59	123·7	123·8
0·5	120·24	120·35	116·82	116·8
1·0	115·13*	115·46	111·20	111·2
2·0	109·30	109·37	105·35	105·1
3·00	103·49	103·55	100·24	100·2
3·75	98·69	98·70	—	—
4·00	—	—	95·20	95·1
5·256	—	—	88·09	87·9

and leaves no doubt that the instrument is a means of accurately measuring electrolytic conductance.

The advantages of a conductance cell without metal–glass seals and reactive or adsorptive metal surfaces are obvious. Although only a glass loop was used in the present work, any relatively non-conducting container could have been used and, apart from the simple requirement that the tube must loop through each toroidal transformer, there is no restriction on its size or shape.

ACKNOWLEDGEMENTS

The method of measurement was devised by Mr. R. Calvert and the apparatus was constructed by Wayne–Kerr Laboratories Ltd.

REFERENCES

(1) Blake, C. G. *Conductimetric Analysis at Radio-freque* (London: Chapman and Hall Ltd., 1950).

(2) Reilly, C. N. *New Instrumental Methods in Elect chemistry*, Ed. P. Delahay, p. 319 (New York: Int science Publishers Inc., 1954).

(3) Jones, G., and Bradshaw, B. C. *J. Amer. Chem. Sc* **55**, p. 1780 (1933).

(4) Jones G., and Bickford, C. F. *J. Amer. Chem. Sc* **56**, p. 602 (1934).

(5) Wishaw, B. F., and Stokes, R. H. *J. Amer. Chem. Sc* **76**, p. 2065 (1954).

A mechanical-electrical transducer of simple design

By M. Manzotti, M.D.(Milan), The Medical School, University of Birmingham

[*Paper received* 6 *March*, 1956]

A probe electrode plunged into a current field experiences a potential which is a function of its position in the field; when it is moved, the variation of potential is also a function of the displacement.

This principle makes possible the design of mechanical-electrical transducers of simple construction and easy assemblage. An application to pressure recording is here described. The sensitivity (5 cm of water per full deflexion) and speed of response (no distortion for variations of pressure up to 220 cm of water per second) can, if necessary, be easily improved.

Mechanical-electrical transformation can be performed on the basis of the correlation existing between voltage and position in a bounded current field. If a probe electrode is used to explore the field by application of the movement to be recorded, the variation of potential exhibited by the electrode is a function of the movement. This function, which is determined by the geometry of the field, can, under proper circumstances, be made linear.

In this particular case, the movement of a metal bellows due to positive and negative respiratory pressure had to be recorded as a measure of the pressure itself. A variable sensitivity of pressure, of 5 cm of water per full deflexion down to 50 cm of water, and such a speed of response as not to distort any possible variation of the respiratory pressures, were required.

CONSTRUCTION

The current field. Distilled water was choosen as a uniform medium for the current field, because of its low conductivity. Evaporation of water was prevented by a layer of paraffin oil. A current alternating at 50 c/s, applied to the medium by two mercury electrodes, produced the field. No electrophoresis or polarization at the electrodes was experienced. Vertical mounting was preferred in order to decrease the friction of the water on the exploring electrode.

The geometry of the field, Fig. 1, was designed so as to have a parallel flow of the lines of current in the region of the exploring electrode, thus obtaining a constant gradient of potential. Under these conditions, the electrical resistance of the field was about 1 MΩ.

The exploring electrode. This was made of a silver wire, 0·1 mm diameter, strengthened and insulated by threading it into a drawn glass capillary tube. At one end the glass was sealed on to the silver so that only the very tip of the wire produced electrical contact. The other end of the capillary tube, from which the silver wire leads to the input of the recording equipment, was secured by insulating w to the centre of the closed end of the bellows. The axis the exploring electrode was in line with the direction of t displacement of the bellows. The bellows were fixed abo the current field and the exploring electrode dipped into t field, with its recording tip in the region of the consta potential gradient. For maximum efficiency alineme

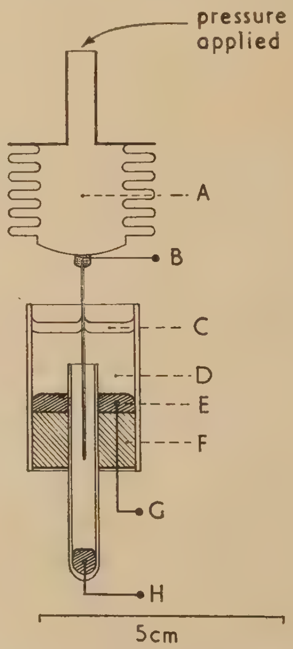


Fig. 1. Cross-section of the mechanical-electrical transducer for recording changes in pressure

A, metal bellows; *B*, probe electrode; *C*, paraffin oil; *D*, water; *E*, mercury; *F*, rubber; *G*, *H*, field electrodes.

etween current lines and exploring electrode axis was aintained.

THE RECORDING EQUIPMENT

Amplification is not a matter of great concern. In this stance the displacement of the bellows was about 0·6 mm r 50 cm of water applied pressure and the field gradient out 0·17 V/mm; this resulted in roughly 10 mV input gnal per 5 cm of water pressure, which is well above those lues for which amplification requires critical attention. oreover, if greater sensitivity is needed, a more sensitive llows or a rubber membrane could be used and the field adient increased.

The upper limit of the speed of the transducer is set by the equency response of the moving parts. Below this value e characteristics of the field and of the rectifying unit play important role. By increasing the frequency of alternation the current field, even the damping introduced by a filter llowing a single-wave rectifier could be made small enough prevent appreciable distortion of a fast input signal. This chnique, however, has the disadvantage that interference om the mains will easily appear on the rectified output and eater complications have to be introduced in the circuit in der to erase it.

It was preferred instead to energize the field with alternating uare waves, obtained by clipping the 50 c/s a.c. from the ains, and to use a full-wave rectifier.

This allows:

(i) stabilization of the field by the limiting action of the clipping device;
(ii) complete erasion of mains interference;
(iii) reasonably smooth output and no distortion for variations of pressure up to 220 cm of water per second.

PERFORMANCE

The calibration curves of the system are given in Fig. 2. a more linear relation between pressure and displacement is to be attained, a bellows having a higher displacement-essure coefficient should be used.

Some drift of the zero line may be experienced in either one or the other direction if the alternating field is not symmetric with respect to earth. By proper adjustment of the earthing point of the field a condition of no drift can be reached. In the same way, polarization of the probe electrode, if any, can be compensated. At room temperature, no variation of the readings was detected for variations of ±10° C.

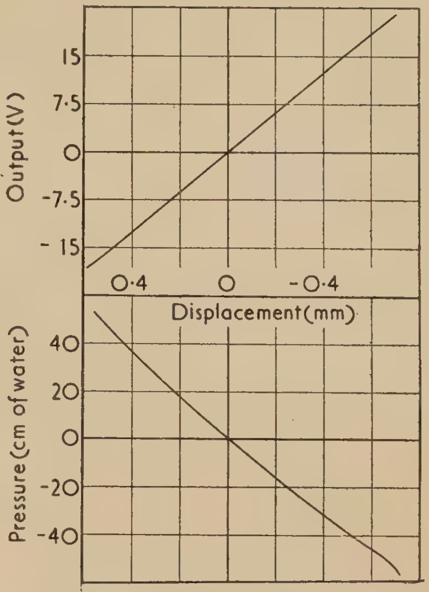


Fig. 2. Pressure-displacement and displacement-recorded output voltage characteristics

The greatest advantage of this system of transforming mechanical movements into electrical signals is that the actual transducer does not require any skilful machining and can be easily and quickly assembled in any desired shape or size.

A simple, small dielectric test cell for liquids

By S. Baxter, M.Sc., F.Inst.P., and P. D. Wilmot, B.Sc., A.Inst.P.,* Monsanto Chemicals Ltd., Ruabon, Denbighshire

[*Paper received* 18 *April*, 1956]

An easily constructed guard ring test cell, which is both robust and precise, is described. Its calculated capacitance has been compared with values estimated from results using liquids of known dielectric constant and good agreement obtained.

uring work on the electrical properties of chlorinated phenyls and similar dielectric fluids, the need arose for a ll of simple construction suitable for use with small antities of liquid. Details of construction of cells for use th larger quantities of liquid have been described.(1,2) ells for use with small quantities of liquid have also been scribed(1,3) but these require the accurate machining of artz bushes or rings which is a difficult matter. In the se of two electrode cells the choice of supports is limited high quality insulators such as quartz or Teflon. If a ard ring cell is designed, then, since the two electrodes can be mounted separately to the guard ring, the choice of insulating supports is not so limited and ceramics or similar materials may be used provided they are above the liquid surface.

The cell described in this paper can be readily constructed in any good instrument workshop; the insulating supports are made from Mycalex bushes. The essential features of the cell are shown in Fig. 1(*a*). The assembly depends on suspending an outer cup *A* containing the liquid, an inner electrode *B* and a guard ring *C* from three separate flat rings, *D*, *E* and *F* respectively, which are held rigidly together using ceramic bushes as indicated in Fig. 1(*b*). The rings *D* and *E* are each mounted to ring *F* by three insulating supports, the six supports connected to F being spaced equidistantly. One of the supports of each ring is extended to provide a terminal as shown in Fig. 1(a). The internal diameters of the rings are arranged in ascending order from the bottom ring so that all the electrodes can be readily removed from the ring assembly which is normally left in a fixed and mounted position. The inner electrode B has dimensions such that when correctly positioned within electrode A a 1 mm gap is left. The inner electrode B is screwed to ring G and can be locked by locknut H. The inner electrode is finally mounted and positioned by the use of space rings and the careful setting of the three mountings I. It is important that the guard ring penetrates the surface of the liquid so as to eliminate surface conduction effects. The liquid level in the cell is fixed by the position of three overflow holes J which allow excess fluid to pass to the inside of the hollow inner electrode. All the metal parts of the cell assembly are made from stainless steel.

---

* Now at Mond Nickel Co., Ltd., London.

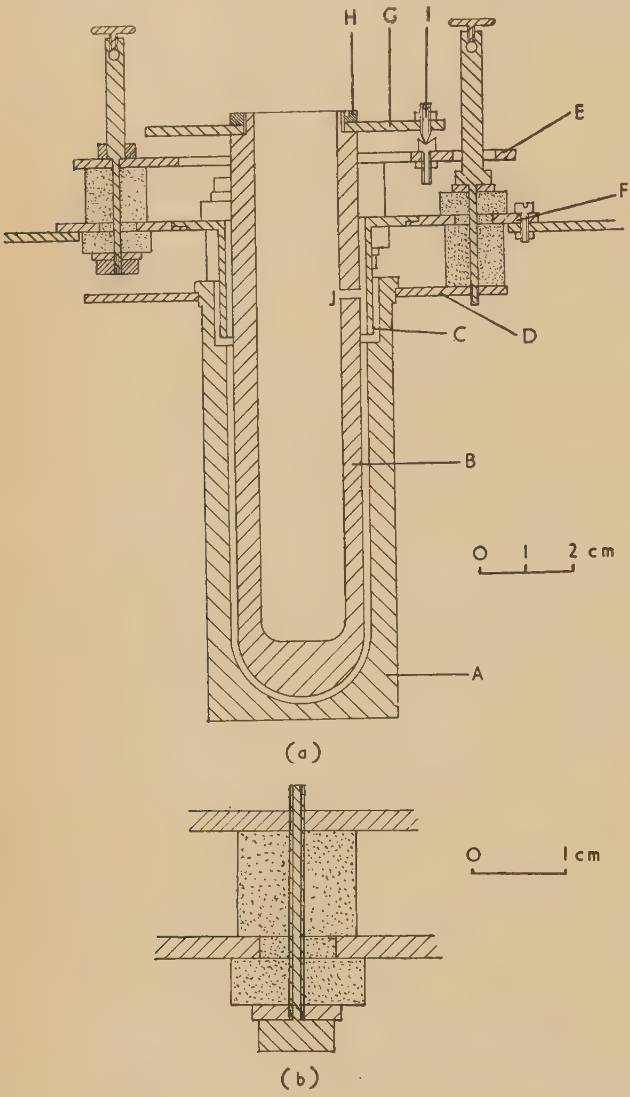


Fig. 1. Dielectric test cell

(a) Assembly of cell. (b) Detail of ceramic bush.

The cell is mounted in an air thermostat which can be accurately controlled, and a thermometer down the inner well of electrode B indicates the temperature of the system. Appropriate leads are taken from the cell to an aud frequency Schering bridge fitted with a Wagner earth, t guard ring being earthed, the outer electrode at the l potential and the inner electrode at the high potential.

The calculated cup capacitance C_0 was 51·5 pF. indirect estimate of this value was obtained by calibration the cell by the use of standard liquids, namely, benze chloroform, ether and n-pentane, the measurements bei carried out at room temperature. As the measured capacitan is the sum of the cup capacitance C_0 plus the parasitic capa tance C_p, a measurement with the cell empty and then o with the cell filled with a liquid of known dielectric consta gives sufficient data to enable the cup capacitance in air a the parasitic capacity to be evaluated. This has been do with the ten independent pairs of measurements of the c capacity when filled with air and the four liquids mentione The results are shown in Tables 1 and 2.

Table 1. *Measured values of cell capacitance with liquids known specific inductive capacity*

Filling	*Capacitance* (pF)	*Specific inductive capacity*
air	54	1
benzene	120	2·284(4)
ethyl ether	226	4·335(4)
chloroform	263	5·05(5)
n-pentane	98	1·846(6)

Table 2. *Experimental values of cup and parasitic capacita*

Pairs of measurements used	*Cup capacitance,* C_0 (pF)	*Parasitic capacitan* C_p (pF)
air–benzene	51·4	2·6
air–ether	51·6	2·4
air–chloroform	51·6	2·4
air–pentane	52·0	2·0
benzene–ether	51·7	1·9
benzene–chloroform	51·7	1·9
benzene–pentane	50·3	5·1
ether–chloroform	51·7	1·9
ether–pentane	51·5	3·0
chloroform–pentane	51·5	2·0

The value of capacity of the empty cell has been taken 51·5 pF and the parasitic capacitance as 2·5 pF. The c constant for resistivity measurements was determined fro the C_0 value and is 583 cm. These constants are independe of temperature and have remained unchanged over two yea of continuous use.

ACKNOWLEDGEMENTS

The authors' thanks are due to Mr. R. N. Woolmer w constructed the cell and to Mr. A. J. R. Deacon who h made extensive use of the cell.

REFERENCES

(1) American Society for Testing Materials. Standa (D150–54 T), Appendix III.
(2) Baxter and Vodden. *J. Sci. Instrum.*, **29**, p. 379 (195
(3) Hartshorn and Rushton. *J. Sci. Instrum.*, **16**, p. 3 (1939).
(4) Turner. *Z. Phys. Chem.*, **35**, p. 385 (1900).
(5) Cauwood and Turner. *J. Chem. Soc.* [*London*], **10** p. 276 (1915).
(6) Dornte and Smyth. *J. Amer. Chem. Soc.*, **52**, p. 35 (1940).

Laboratory and workshop notes

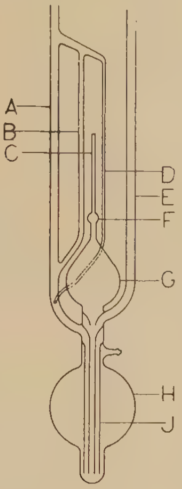
A McLeod gauge for measuring a wide range of pressures

By H. A. WYLLIE, M.Sc., Imperial Chemical Industries of Australia and New Zealand Ltd., Melbourne, Australia

[*Note received* 10 *February*, 1956]

ı McLeod gauge of conventional design is used for measur- pressures up to several millimetres of mercury, the simple ory of the instrument does not apply because the pressure gas over the mercury in the open capillary cannot be glected. Barr and Anhorn(1) have described a gauge to ich the simple theory does apply at pressures in this her region. In this instrument the space above the niscus in the open capillary is isolated from the rest of the tem and kept evacuated.

The gauge shown in the figure makes use of the same idea. wever, the lower section is more compact than the lower tion of the instrument described in Ref. (1). The upper tion follows a design given by Heldman.(2)



McLeod gauge for measuring a wide range of pressures

The tube *A* is connected to the vacuum line and the tube *E* the apparatus where the pressure is to be measured. The be *B* is of the same diameter as the tubing between bulbs and *G*. The diameter of tube *C* is smaller than that of *B*, ilst the diameter of tube *D* is the same as that of *C*. When pressure measurement is carried out, mercury from the servoir *H* flows into *G* and *E* through the inner of the ncentric pair of tubes *J*. Mercury flows into tubes *A*, *B* d *D* through the annular space between the tubes *J*. The gher pressures are measured by raising the mercury surface an etched mark on the tubing between bulbs *F* and *G*. e height of the mercury column in tube *B* is then multiplied the appropriate factor.

The author wishes to thank Mr. E. F. Dawes for carrying t the glass-blowing.

REFERENCES

) BARR, W. E., and ANHORN, V. J. *Scientific and Industrial Glass Blowing and Laboratory Techniques*, pp. 203–205 (Pittsburgh: Instruments Publishing Co., 1949).

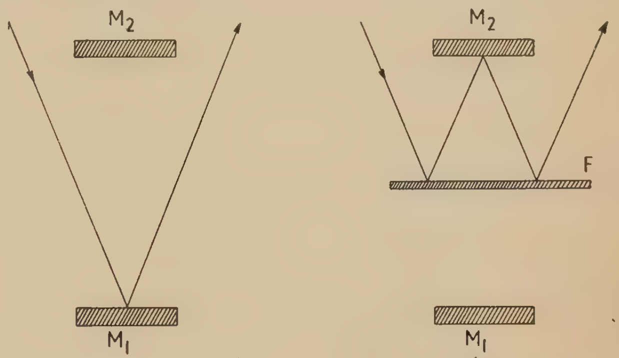
) HELDMAN, J. D. *Techniques of Glass Manipulation in Scientific Research*, p. 108 (New York: Prentice-Hall, Inc., 1946).

An automatic absolute reflectometer

By J. H. JAFFE, B.Sc., Ph.D., A.Inst.P., and U. OPPENHEIM, M.Sc., Ph.D., Weizmann Institute of Science, Rehovoth, Israel

[*Note received* 8 *November*, 1955]

A simple absolute reflectometer has been described briefly by Strong.(1) Two mirrors M_1 and M_2 each having a reflectance R_0 are set opposite to each other [Fig. 1(*a*)]. A light beam incident on M_1 has an intensity proportional to R_0 after reflexion. A sample F is placed as shown in Fig. 1(*b*) with its reflecting surface equidistant from M_1 and M_2. The incident beam suffers two reflexions at the sample and one at M_2. The intensity of the emerging beam is proportional to R_0R^2 where R is the reflectance of the sample. Thus the ratio of the intensities of the light passing through, with and without the sample in position, is equal to the absolute value of R^2. If the reflectances of M_1 and M_2 are not identical, the instrument can be calibrated simply by repeating a measurement with these mirrors interchanged.



(a) (b)

Fig. 1. Principle of Strong's reflectometer. The plane mirrors M_1 and M_2 are set parallel to each other. F is the sample under examination

The authors have constructed on this principle an instru-

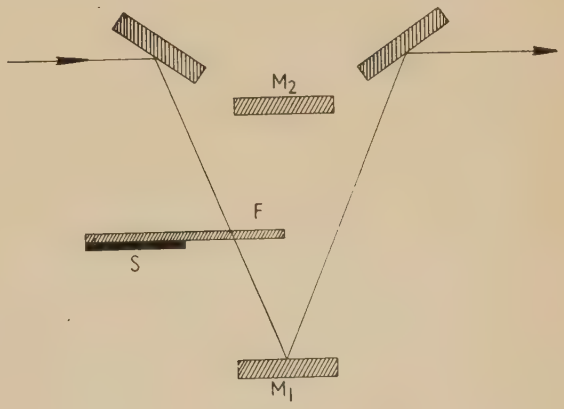


Fig. 2. Practical arrangement of the absolute reflectometer. The sample F slides in and out of position automatically. The transmittance is measured in the position shown. S is an opaque shutter which blocks out an unwanted transmitted beam

ment that measures the reflectance R and the transmittance T of semi-reflectors as a function of wavelength. The sample is mounted on a carriage and by means of a mechanism involving a Maltese cross it is moved automatically and repeatedly through the following cycle, stopping a short while in each position. First, the sample is out of the beam altogether [Fig. 1(*a*)]. In the second position the sample intercepts the beam once, as shown in Fig. 2, and in the third position it is fully inserted [Fig. 1(*b*)].

The reflectometer is placed in collimated light in front of a monochromator. As the latter scans through a wavelength region the sample is kept moving through its cycle. A pen recorder plots successive segments of the following three curves: R_0, R_0T and R_0R^2 *versus* wavelength. The opaque shutter S is placed behind half of the sample in order to block out an unwanted transmitted beam. The instrument measures the absolute values of R and T at an angle of incidence of 20°. It has been of great service in an extensive investigation of the optical properties of semi-reflectors in the near infra-red region.(2)

REFERENCES

(1) Strong, J. *Procedures in experimental physics* (New York: Prentice-Hall, Inc., 1944).

(2) Oppenheim, U. *Ph.D. Thesis* (Hebrew University, Jerusalem, 1955).

A flexible mount for specimens in single crystal and powder X-ray cameras

By E. Aruja, M.Sc., Ph.D., A.Inst.P., Building Research Station, Watford, Herts

[*Note received* 3 *February*, 1956]

Several attachments for single crystal goniometers have been described(1–3) which enable oscillation photographs to be taken about different crystallographic directions without resetting the crystal on its glass fibre. A method used in this laboratory for a number of years deserves to be more widely known.

This method consists of using a lead wire which takes the place of the plastic compound usually employed for joining the specimen to the goniometer. One end of a piece of lead wire, about 1 mm in diameter and 1–2 cm long, is soldered to a small brass block, which is drilled to take the peg of the goniometer head and is provided with a grub screw. To the other end of the lead wire is glued a short piece of glass fibre which carries the crystal. By gripping this end of the wire with tweezers one can tilt the crystal into a variety of orientations, using the goniometer arcs for final adjustments. If the crystal has a recognizable outline there is little difficulty in orientating the crystal at will in positions outside the reach of the arcs. In any case the lead wire obviates the need to push the arcs and the cross slides into the extreme position. If a similar piece of lead wire is fixed to the specimen holder of a powder camera, the alinement of specimen parallel to the axis of rotation is made easier.

This note is published with the permission of the Director of Building Research.

REFERENCES

(1) Mackay, A. L. *J. Sci. Instrum.*, **29**, p. 164 (1952).

(2) Gross, K. A. *J. Sci. Instrum.*, **29**, p. 414 (1952).

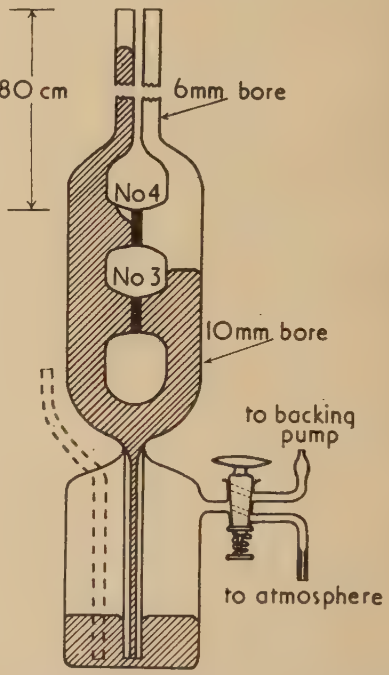
(3) Grenville-Wells, H. J. *Acta Cryst.*, **8**, p. 519 (1955).

A mercury cut-off for transferring gas at atmospheric pres into a high vacuum

By N. N. Greenwood, M.Sc., Ph.D., Department
Chemistry, University of Nottingham

[*Note received* 29 *December*, 1955]

Most designs of mercury cut-off involve ground glass fl
magnetically operated caps or displacement plungers, and
unsuited to systems where the pressure difference between
two limbs is more than a few centimetres of mercury. Se
and Muraca(1) have described a cut-off which enables
pumps to be turned off and brought to atmospheric pres
without affecting the degree of vacuum in the system, but
does not permit the transfer of gas from one side to the ot
Stock(2) devised a Y-tube fitted with two sintered glass d
which enabled gas to be transferred, but only at the exp
of greatly reduced pumping speed and ultimate vacuum.
rather cumbersome device which partly overcomes
difficulty involves the recycling of large quantitie
mercury.(3)



Mercury cut-off for transferring gas at atmospheric pressure into a high vacuum

The cut-off shown in the diagram permits controll
transfer of gas in either direction across any pressure differen
from zero to about 800 mm of mercury without loss
pumping speed or the use of excessive amounts of mercu
It consists of a Y-tube, two limbs of which are spanned
parallel by sintered glass disks (No. 4: pore diameter 5–10
No. 3: pore diameter 20–30 μ). The third limb is connect
to a reservoir containing about 150 ml. mercury and this
manipulated by means of a backing pump or air pressure
a spring-loaded two-way tap. Compressed air (+20 cm
mercury) is normally only required if the cut-off is to rema
closed whilst there is a pressure difference of one atmosph
between the two limbs.

Gas is transferred from one section to the other by open
the spring-loaded tap to the atmosphere until the merc
level has fallen to the position indicated in the diagram. T

then permeates the sintered disk and rises up the column nercury into the second limb. Even when this limb is ally under high vacuum (10^{-4} mm of mercury) the mercury ely oscillates in the tubes, and there is none of the disas- is catapulting of mercury which is usually associated with opening of an unconstricted tube under similar circum- ces. After some minutes there is usually sufficient pressure gas in the low-pressure side to damp the movement of cury still further and the level can then be lowered to nit more rapid transfer through disk No. 3. It should ioted, though, that this more porous disk will only support olumn of about 30 cm of mercury; with higher columns, cury is forced back through the disk counter to the gas ng transferred. It is clear from the design that when the off is fully opened there is unrestricted contact between two limbs so that pumping efficiency is unimpaired.

simple manometer may be incorporated in the apparatus he position shown by the dotted lines but this feature is no means essential. It is a safety indicator to show the ssure of air within the reservoir, as this is not always ctly apparent from the position of the mercury in the two er limbs when these are at intermediate pressures.

n a modification of the apparatus, the mercury reservoir spring-loaded tap may be replaced by a movable reservoir nected to the cut-off by rubber tubing. This eliminates need for the backing pump and compressed air but is esirable in work of highest precision because of the risk contaminating the mercury with moisture, etc., from the ber.

REFERENCES

Serfass, E. J., and Muraca, R. F. *Rev. Sci. Instrum.*, **16**, p. 225 (1945).

Stock, A. *Ber. Deutsch. Chem. Gesell.*, **58**, p. 2058 (1925).

Wilson, J. L. *J. Phys. Chem.*, **35**, p. 3353 (1931).

Phasing device for small synchronous motors*

y D. T. R. Dighton, M.Sc., A.R.C.S., A.Inst.P., and
W. G. Waters, Kodak Ltd., Harrow, Middlesex

[*Note received 5 January*, 1956]

s common practice in photoelectric instruments to make of a motor-driven flicker wheel to modulate the light ms; by this means only alternating signals are developed the drift and stability problems of d.c. amplifiers are ided. A useful and widely used system is one in which vo- or four-pole synchronous motor is used to drive the ker wheel, the motor being operated from the 50 c/s a.c. ns supply. With a two- or four-sector flicker wheel this es a 50 c/s light modulation; this frequency is very con- ient, as it permits the use of a reference signal derived ct from a mains transformer. The comparison with this rence signal is normally carried out in some form of se-sensitive detector circuit or, in servo-systems, with a -phase servo-motor.

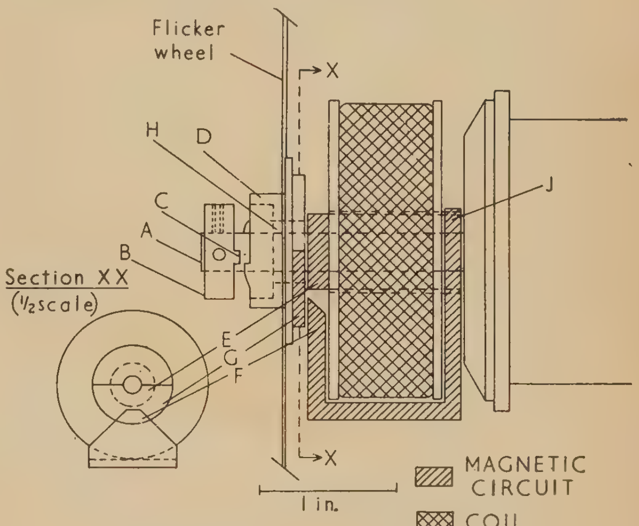
convenient type of motor for driving the flicker wheel is the two-phase type in which one stator winding is fed ct from the a.c. supply and the other is fed through a able condenser. The resulting rotating field drives the or. Type FC34/0, manufactured by Evershed and Vignoles ., has been found very satisfactory.

ne difficulty does, however, arise in this kind of application re the modulation frequency required is the same as that of the supply to the motor. The poles of the rotor are not identified in any way and the motor can run equally well with the rotor poles interchanged: these alternative running states give rise to modulation signals differing by 180°. These in turn, of course, affect the polarity of the output indication. In the case of a servo-system the result is that the tendency is to run away from, rather than to seek, the balance position.

This difficulty would not arise if the motor could distinguish the poles of the rotor. Thus a unit with a permanent magnet rotor or a wound rotor fed with d.c. current would be satisfactory. However, no small synchronous motor of this type appears to be commercially available.

The difficulty can be overcome by other methods involving commutating switches mounted on the motor shaft or the derivation of the reference signal from a subsidiary optical system modulated by the same flicker wheel. These and other similar methods have all been used in photoelectric instruments with varying degrees of satisfaction and reliability.

It was felt that it should be possible to design a simple attachment to the motor itself which would sense the phase of rotation and correct it if necessary. Such a unit has been made and is described in this note.



Side view and section of phasing device

A, extension of motor shaft; *B*, fixed clutch member; *C*, clutch projection; *D*, free clutch member; *E*, soft iron cylinder; *F*, *J*, soft iron yoke; *G*, soft iron semicircle; *H*, recess for spring.

To the motor spindle *A* (or an extension of it) is attached a clutch member *B* carrying two projections *C* 180° apart. A second clutch member *D* which carries the flicker wheel is free to rotate and slide on the motor spindle. Two projections on this second clutch member permit it to engage with *B* and take up one of two angular positions 180° apart with respect to the motor shaft. Which of these is the correct one is sensed by an electromagnet energized from the 50 c/s supply through a rectifier. This electromagnet has its poles at *E* and *F* and can attract the free clutch member *D* by means of a semicircle *G* of soft iron let into the main brass body. The two clutch members are normally held in engagement by a light spring positioned in the recess *H*.

The phasing device operates in the following way. The motor is first switched on and the free clutch member and flicker wheel take up either the correct or the incorrect phase setting—which occurs is a matter of chance. The coil is then energized through the rectifier by means of a push button switch. The 50 c/s pulses of magnetic field which result coincide as the clutch members rotate with either the semicircle of brass or that of steel. In the former case, since the brass is non-magnetic, the clutch will remain engaged. In the latter case the steel will complete the magnetic circuit and the clutch be withdrawn. The friction of the air on the flicker wheel is sufficient to slow the free clutch member relative to the spindle, thus causing the clutch to re-engage, between pulses of the magnetic field, in the alternative position at 180° to the original. The selected running phase can be changed by reversing the rectifier.

---

* Kodak communication No. 1773H.

The spindle *A* is of $\frac{1}{4}$ in. diameter silver steel and is attached to the spindle of the type FC34/0 motor by means of a mild steel collar. The effect is to extend the spindle to a length of $1\frac{3}{4}$ in. beyond the motor body.

The fixed clutch member *B* is machined from tool steel and hardened to prevent burring. It is attached to the spindle by two grub screws which provide a means of adjustment. The free clutch member *D* is made up of three pieces. A shell of brass has brazed to one face the semicircular disk *G* of mild steel. The opposite face of the brass shell receives the hardened steel plug which is the counterpart of the fixed clutch member *B*.

The energizing coil is of 42 s.w.g. enamelled copper wire and 7800 turns are wound on to an ebonite former which is supported concentrically with the motor spindle.

During assembly, the clutch members and the pole-piece must be set in the correct relative angular position. This is best carried out by disconnecting one stator winding and allowing the rotor to take up one of its two stable positions. The pole-piece is then fixed to the motor with the pole *F* symmetrically placed with respect to the semicircular steel insert when the clutch members are in full engagement.

To check the operation of the device a small neon lamp operated in series with a rectifier, and thus giving light pulses at 50 c/s, may be viewed through the flicker wheel. If a switch is connected to reverse the polarity of the rectifier feeding the coil, the lamp should be alternately visible and invisible as the switch is operated successively.

A water-driven device for filling, aerating and agitating baths

By A. L. SIMS, University of Wales, Cardiff

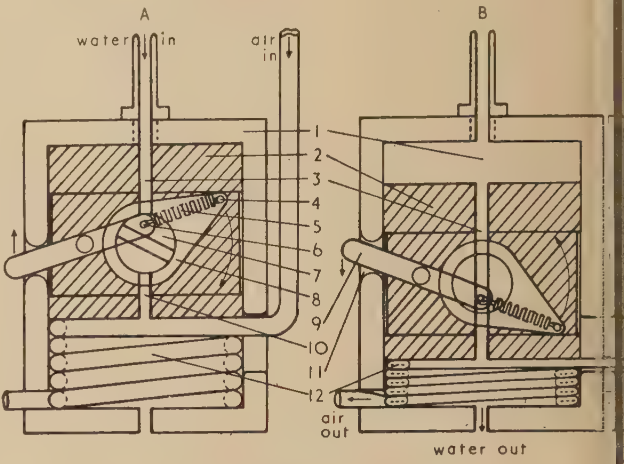
[*Note received* 16 *January*, 1956]

The figure shows an instrument consisting of a Perspex cylinder (1) in which the Perspex piston (2) is made to reciprocate by water pressure on one side and by the recoil of an elastic agent (12) on the other.

Part *A* of the figure shows the piston at the commencement of its stroke and ready to receive the water pressure and part *B* shows the piston at the end of its stroke and ready to receive the pressure from the recovery of the elastic agent, in this case a rubber tube coil, this having previously been compressed during the down stroke. Any elastic agent may be used to return the piston, namely, a metal bellows, spring, etc., according to the work the instrument is called upon to perform.

Fitted through the piston at right-angles to its stroke is a one-way stop-cock but, in this case, the usual turning knob is a lever (8) having a projecting spigot (4) near its end, as anchorage for a spring (5). A portion of the piston is machined away locally to enable this lever (8) to turn its plunger (7) from the off to the on position and *vice versa*, without fouling the cylinder wall.

To enable the stop-cock plunger to be turned quickly r the end of each stroke of the piston, a conventional s action mechanism is also fitted in the machined-away port of the piston. This gives a two-way pull on the stop-c plunger lever (8) by an extension spring (5) operated b pivoted lever (9). One end of this pivoted lever proj through a slot (11) in the cylinder wall and the other end a spigot (6) fitted, in order to link the levers by the spr



Two views of instrument

Thus, reciprocation of the piston tips the lever (9) a increasing spring tension overcomes the friction of the st cock plunger in its hole. The plunger quickly rotates a allows the water to escape into the bath by the two holes and (10) through the centre of the piston.

The rate of reciprocation of the piston is easily regula by opening or closing the supply tap; thus many other possi applications will be apparent where movement is required a the only source of power available is a water supply.

The instrument which was designed to aerate and ag water in a metal bath, is connected by a rubber tube t domestic or laboratory tap and uses as motive power c tinuously running water from the tap.

The water then passes on into the bath, on the bottom which the instrument rests immersed, whilst the air inlet the rubber tube coil extends above the overflow level and clipped to the side of the bath.

Laboratory furnace with rotating table for producing conducti glass

By E. ALEXANDER, Dr.Ing., and I. T. STEINBERGER, M.Sc.,
The Hebrew University, Jerusalem, Israel

[*Note received* 5 *March*, 1956]

In electroluminescence, photoconductivity and related inves gations, conducting glass prepared by the method of Gome was found extremely useful. The furnace described in th note was constructed in order to produce in the laborato homogeneous and transparent conducting coatings on fl glass surfaces up to 30 cm diameter by Gomer's method.

The furnace (see figure) consists of a horizontal rotati cast iron disk of 30 cm diameter contained in a cylindric iron box. Flat heating elements insulated by mica a ched underneath the disk. The power consumed by the ing elements is about 2000 W. The heating elements can lisconnected before setting the disk in rotation. The disk rovided with an axle rotating on ball bearings arranged ut 5 cm beneath the box. The axle is rotated by a geared or at 3 rev/min. The box consists of a flat base and a ndrical lid, both covered with asbestos and glass wool lation.

---

* GOMER, R. *Rev. Sci. Instrum.*, **24**, p. 993 (1953).

Rotating table furnace with lid open showing four glass disks of 11 cm diameter each

/hen preparing the glasses, they are arranged on the top ne disk, covered with the lid and the heating current turned until the air temperature measured 2 cm above the disk hes 400° C. Then the heating elements are disconnected the rotation is started immediately. A mixture of oxygen Stannic chloride vapour is then streamed into the furnace ugh a radial opening in the lid, according to the method n by Gomer.

he glasses obtained compare favourably in uniformity, sparency and conductivity with commercial "conducting ses."

ansducer for the sequential measurement of two levels of thrust

y J. G. Clouston, M.Sc., A.S.T.C., Department of Supply, Australia

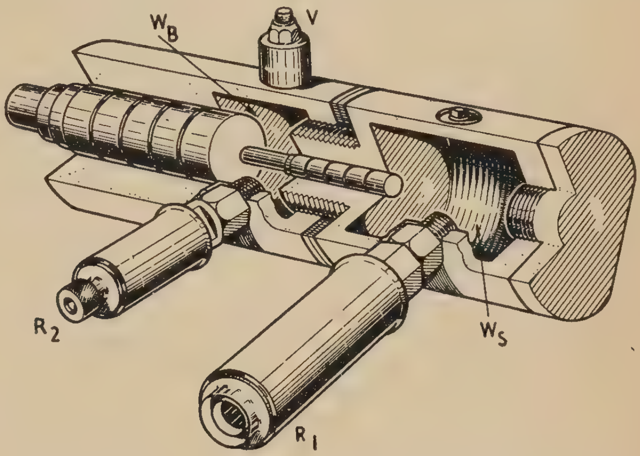
[*Note received* 26 *January*, 1956]

of-stand testing of composite boost-sustainer rocket ors requires the sequential measurement of two levels of st. In such motors the thrust of the boost motor is ral times greater than that of the sustainer motor. Conently, to measure the thrust by any conventional method ansducer designed and calibrated to accommodate the er boost force would be required. As a result, in any ential measurement of thrust from the two motors in em, the displacement of the recording channel due to the ainer thrust would be several times smaller than that due ne boost thrust.

was considered that an accurate assessment of such a or system as a whole could only be made if some means provided for increasing the sensitivity of the recording em at the end of the boost period. This has been achieved he design of the tandem piston thrust transducer illusd in the figure. The advantage of the method is that the ation in sensitivity is absolute since it depends solely on the change from one accurately known piston area to another equally accurately known.

Thrust is measured in this case in terms of hydrostatic pressure. The thrust-force of the rocket motor acts on a piston, thus causing pressure in a Vaseline-filled cylinder, and this pressure is detected by means of the pressure sensitivity of a carbon resistor. The resistor gauge forms one arm of a Wheatstone bridge circuit. The out-of-balance signals from the bridge, due to the pressure acting on the gauge, are amplified by a direct-coupled amplifier and displayed on a cathode-ray oscillograph.

Referring to the figure, the areas of the two pistons are in the same ratio as the estimated boost thrust is to the sustainer thrust. Each piston works into its corresponding grease-filled well, W_B and W_S, to develop a pressure which is recorded by the resistor gauge R_1 in W_S. In the initial condition the remotely-operated solenoid valve V venting the grease-filled well W_B is closed and there is a slight separation between the pistons. When the boost force acts on the larger piston the pressure developed in W_S equals the pressure developed in W_B, and is unaffected by the presence of the smaller piston. Therefore the pressure gauge in W_S indicates the pressure developed by the boost force and the calibration is such that a full-scale deflexion of the recording trace occurs.



Double piston transducer for measuring two widely different levels of thrust

The second condition occurs when the solenoid valve is open, and vents W_B to atmosphere. In this circumstance the larger piston moves until it bears against the smaller piston. The pressure developed in W_S is now due to the sustainer force on the area of the smaller piston and a full-scale deflexion is again recorded at maximum sustainer motor thrust. Since the ratio of the pistons is known, a single calibration of the gauge suffices.

During the boost period the signal from the pressure gauge R_2 in W_B arms and trips an electronic trigger circuit* as the pressure due to the boost motor rises and falls through a preset value. When the circuit trips the solenoid valve V is opened. Consequently, the operation of the solenoid valve is independent of the burning time of the boost and premature or delayed opening cannot occur.

This note is published with the permission of the Chief Scientist, Department of Supply, Australia.

---

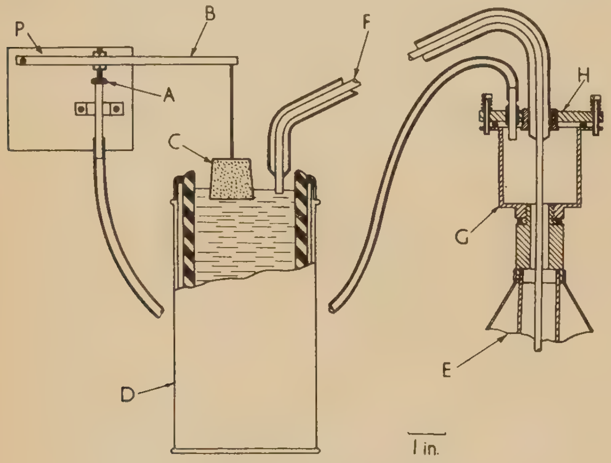
* Yu, Y. P. *Proc. Instn Radio Engrs*, 37, p. 1046 (1949).

A liquid level regulator for replenishing cold traps

By H. C. Probyn, Services Electronics Research Laboratory, Baldock, Herts

[*Note received* 7 *March*, 1956]

For overnight operation of large cold traps, particularly of the conduction cooled type,* it is necessary to keep the coolant level constant by automatic feed from a large reservoir flask. An automatic level regulator working on the gas thermometer principle has been described by Feld and Klein† but has been found to have various disadvantages. It is not capable of being used with the standard large metal liquid-air container, since it will not allow sufficient pressure to be built up in the container to lift a head of coolant equal to the depth of the container. Initial setting-up is tedious, and operation is subject to considerable time-lag when the thermometer bulb is used in a flask with a covered top. Furthermore, when not in use the device must be stored vertically unless it is to be refilled with mercury for each occasion of use.



Liquid air replenisher

These disadvantages are obviated in the simple float type regulator shown in the figure, where a flask *D* is fed through a vacuum-jacketed silvered glass pipe *F* from the standard container *E*, to the threaded mouth of which screws a copper cylinder *G* flanged to take a Perspex cover *H*, which is sealed by a rubber ring. Arm *B* is of Tufnol, pivoted at *P* and carrying a disk *A* of soft rubber capable of sealing the end of a metal pipe communicating *via* rubber tubing with the cylinder *G*. Float *C* is a cork, attached by a rigid stainless steel wire to the arm *B*, and positioned so that when the liquid in *D* reaches the required level, the disk *A* is lifted from its seating and build-up of pressure in *E* ceases, and thus coolant is no longer fed through *F*.

The normal rate of evaporation of liquid oxygen in a standard metal vacuum container provides enough displacement for the rates of topping up normally required for traps up to 7 in. diameter without the introduction of extra heat.

If tube *F* should block, disk *A* lifts as a safety valve: a further safety precaution is the incorporation of spiral springs beneath the heads of the bolts holding the cover *H* in contact with its rubber sealing ring. There appears to be no tendency for icing of the inside of the threaded neck of the reservoir, but if this became a danger under abnormal conditions a strip heater could easily be fitted round cylinder *G*, which made of thick copper with this in mind.

Permission has been obtained from the Admiralty for publication of this note.

---

* Pollard, J. *Rev. Sci. Instrum.*, **24**, p. 996 (1953).

† Feld, M., and Klein, F. S. *J. Sci. Instrum.*, **31**, p. 474 (1954).

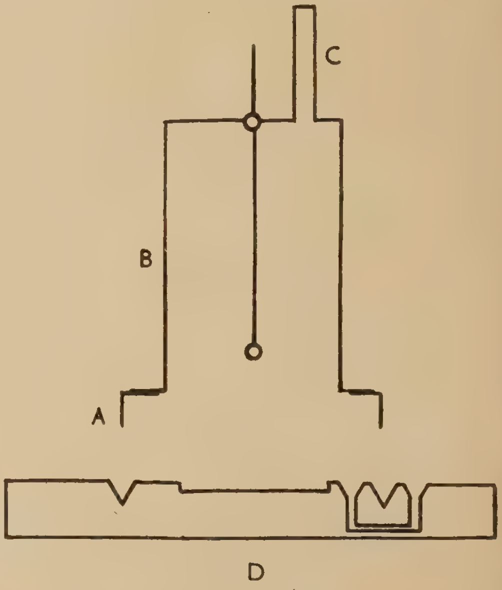
An easily constructed helium flow counter

By E. J. Harris, D.Sc., Biophysics Department, University College, London

[*Note received* 19 *January*, 1956]

It is well known that sources of radiation of low penetra power can be assayed by insertion into a Geiger tube an filling of helium with a trace of a quenching agent (alcohol) permits operation at atmospheric pressure.

A demountable tube for this purpose can easily be m from a discarded metal-bodied, end-window counter such a G.E.C. type G.M.4. In a flanged tin lid *A*, a hole is punc of a diameter slightly greater than the internal diamete the counter. The counter *B* is soldered over the hole, an filling tube *C* is fitted to the original seal-off. A base-p *D* of metal or acrylic resin is made with (*a*) a circular tro of V-section to take the flange of the tin lid, (*b*) a depress to fit the counting planchettes, and (*c*) a U-interconnex ($\frac{1}{16}$ in. diameter) between the area inside the trough and outside air; if this plate is made of insulating materia should be graphited to avoid charge-collection. A few dr of viscous silicone (e.g. D.C. 500) are placed in the circ trough and a drop in the U-connexion.



Helium flow counter

To operate the counter, the sample is inserted and helium–alcohol mixture passed vigorously through the fill tube, lifting the counter from the base and expelling the When counting starts, the gas stream is reduced to occasional bubble through the U-connexion. The consun tion of helium is small because of the efficient flushing a subsequent slow stream required.

When measuring a low-activity source, it is convenient check the start of counting with an additional external γ- source, placed below the base plate. The operating volt is just under 2 kV; this has remained constant over a peri of months during which a particular cylinder of helium been in use.

Correspondence

Coulometric titrations using a pulse technique

oulometric titrations the main difficulties are the mainnce of a steady current and the accurate measurement of . The many devices and circuits reported in the literature therefore necessarily complicated. We have simplified lometric titrations by using constant pulses instead of a dy current. The measurement of the number of coulombs hen reduced to a mere counting of the number of pulses. he circuit uses an Abraham and Bloch multivibrator,* ered by a very highly stabilized high tension source, as enerator of constant pulses. The coulometric titration was connected between the cathode and the earth of one he valves of the multivibrator. A high-speed relay inserted ween the anode and the high tension line of the same valve, erated a Post Office counter. The size and frequency of pulse was controlled by an adjustment of R_1 and R_2 or and C_2 (Fig. 1).

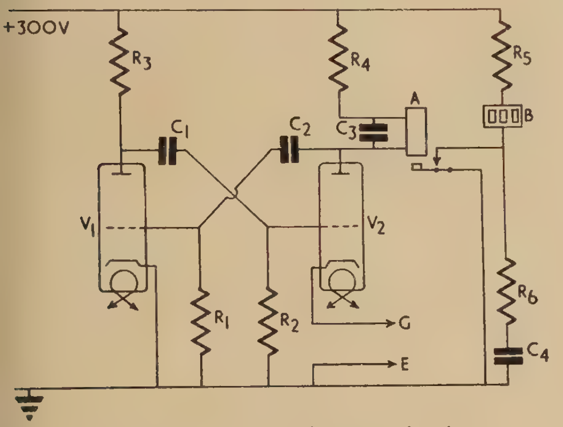


Fig. 1. Pulse coulometer circuit

$C_1 = 1\ \mu F$
$C_2 = 0{\cdot}5\ \mu F$
$C_3 = 2\ \mu F$
$C_4 = 0{\cdot}1\ \mu F$

$V_1, V_2 =$ 6SN7GT
$A =$ Siemens' high-speed relay

$B =$ Post Office counter

$R_1, R_2 = 1\ M\Omega$ (high stability), 1 W
$R_3, R_4 = 10\ k\Omega$, 24 W, w.w.
$R_5 = 10\ k\Omega$, 10 W, w.w.
$R_6 = 330\ \Omega$

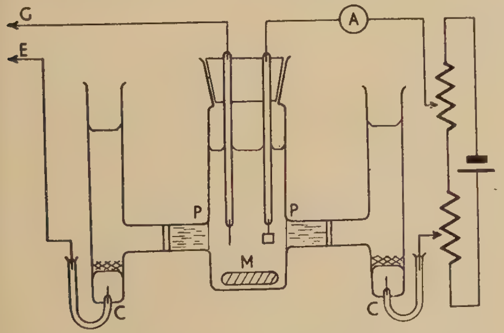


Fig. 2. Titration cell and indicator circuit

, microammeter; *C*, mercurous bromide electrode; *E*, to earth ne; *G*, to cathode of V_2; *M*, magnetic stirrer rotor; *P*, agar-agar plug.

Using the above circuit the titration of 8-hydroxyquinoline with electrolytically generated bromine† was carried out. The titration cell and the indicator circuit are shown in Fig. 2. The end-point of the titration is reached when the microammeter needle shows a permanent deflexion. It is also possible to determine the end-point by plotting the microammeter readings against the number of pulses registered, and extrapolating the straight line to zero current. Quantities of 100 to 400 μg of 8-hydroxyquinoline could be determined by this method with an accuracy better than 1%.

This technique of pulse coulometry could be used for all titrations involving electrolytically generated ions, and the instrument can be developed to perform these titrations automatically. Full experimental details will be published elsewhere.

We wish to thank the Council of the University of Ceylon for research grants, Prof. E. L. Fonseka for his interest in this work and Mr. S. D. Samuel and Mr. H. Winnie for technical assistance.

Department of Chemistry,
University of Ceylon,
Colombo, Ceylon.

M. A. V. Devanathan
Q. Fernando

Abraham, H., and Bloch, E. *Ann. Phys.* [*Leipzig*], **12**, p. 237 19).

† Carson, W. N., Jr. *Analyt. Chem.*, **22**, p. 1565 (1950).

An improved photomultiplier construction

In their paper‡ on the design of photomultiplier tubes, Sommer and Turk have viewed the Venetian blind type structure as an extension of the mesh type structure, in which the mesh has been replaced by the slat structure to intercept a larger proportion of the electrons falling on each stage. In practice, each stage is made opaque when viewed along the axis of the tube by mounting the slats in a frame to make an orthogonally opaque array (Fig. 1). No mention was made in this paper of the need for placing successive dynodes in a particular relationship. We believe that a more efficient and simpler structure could be used by taking advantage of the focusing property of the slat structure.

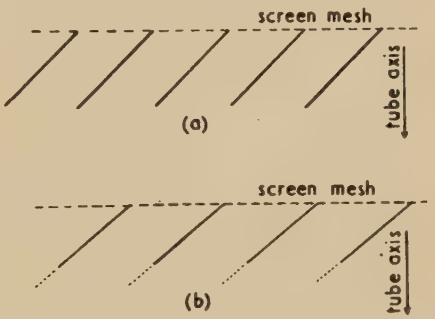


Fig. 1 (*a*). Orthogonally opaque dynode assembly; (*b*) Modified dynode assembly

(Dotted lines indicate conventional slat length.)

Using the rubber model we have investigated this focusing property. We have found the electrons leaving a slatted dynode structure fall into a series of quite narrow beams. It can be seen from Fig. 2 how the mean inclination of these beams to the axis of the tube varies with the inclination A of the individual slats (measured from the plane of the dynode). The inclination of the beams when the slats make an angle of about 40° to the plane of the dynode allows the modified structure to be used as shown in Fig. 3. The exploitation of this focusing property requires very critical location of the dynodes with respect to each other.

---

‡ Sommer, A., and Turk, W. E. *J. Sci. Instrum.*, **27**, p. 113 (1950).

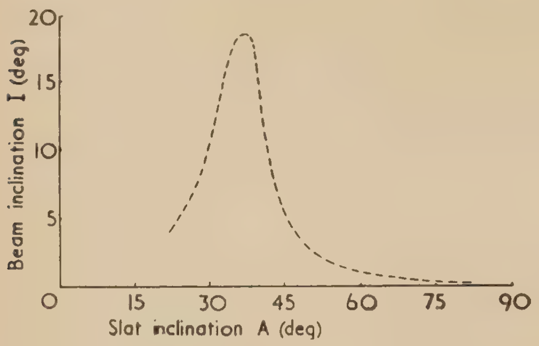


Fig. 2. Variation of beam inclination, I, with slat angle, A

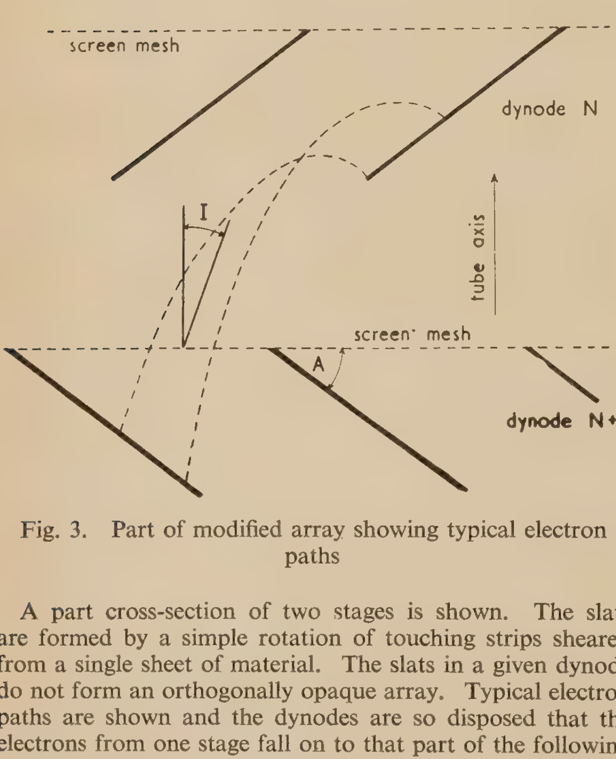


Fig. 3. Part of modified array showing typical electron paths

A part cross-section of two stages is shown. The slats are formed by a simple rotation of touching strips sheared from a single sheet of material. The slats in a given dynode do not form an orthogonally opaque array. Typical electron paths are shown and the dynodes are so disposed that the electrons from one stage fall on to that part of the following stage where the extraction field is greatest. Moreover, due to the inclination of the electron beam to the axis of the tube there is complete opacity to electrons between stages.

The requirement that there shall be no light feedback from the later stages to the cathode is met by the fact that any two stages taken together are opaque in the direction of the tube axis.

The advantages of such a modified structure are, firstly, that each dynode can now be made by a very simple pressing operation and, secondly, that electrons (except those arriving at the first dynode from the cathode) are constrained to travel in regions only where the extraction field is good, avoiding the "dark corners" close to the screen mes
This must result in greater efficiency and faster transit ti
with a lower spread of transit times.

Electrons arriving at the first stage from the cathode
land on all parts of the slats including the "dark corner
but here again the modified dynode assembly has an advant
in that the extracting field is able to penetrate more read
since the slot depth is reduced by an amount shown by
dotted lines in Fig. 1.

An attempt is being made to embody this principle.

20th Century Electronics Ltd.,
Croydon,
Surrey.

A. E. JENNING
C. E. F. MISSO

A cloud chamber illumination unit

We have already* described a new type of flash illuminat
equipment the basic circuit of which contains two flash tub
This equipment has proved suitable for illuminating cl
chambers.

The wiring diagram of the system is shown in Fig.
Components Tr, V_1, V_2, C_2 and C_3 are the usual ones
voltage-doubler circuit. Condenser C_1, which stores
illuminating energy, is charged through the ohmic res

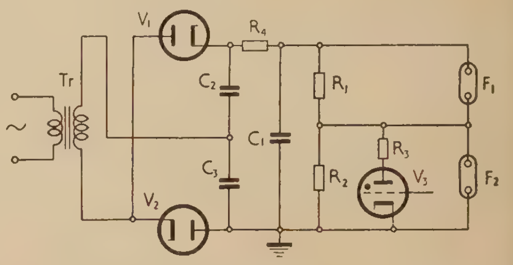


Fig. 1. Wiring diagram of the cloud chamber illumina-tion unit

Tr, V_1, V_2, C_2, C_3 = voltage doubling components
R_4 = charging resistor = 0·1 MΩ
C_1 = working condenser
R_1, R_2 = voltage dividing resistors 50 MΩ
V_3 = thyratron tube (GRG4)
R_3 = ohmic resistor = 0·02 MΩ
F_1, F_2 = flash tubes

R_4. F_1 and F_2 denote the illuminating tubes. The voltage
condenser C_1 is uniformly distributed between the tubes
and F_2 by the high value ohmic resistors R_1 and R_2. Th
latter can be replaced by voltage dividing condensers. T
charging voltage of condenser C_1 must have a value at whi
the illumination tubes F_1 and F_2 would almost break dow

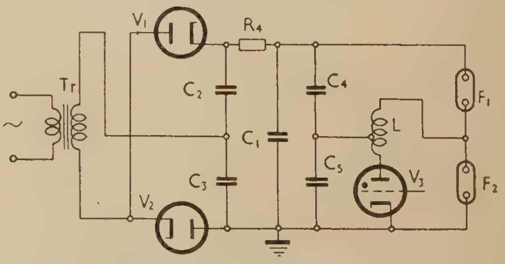


Fig. 2. Cloud chamber illumination unit for the operation of low breakdown voltage tubes

Tr, V_1, V_2, C_2, C_3 = voltage doubling components
R_4 = charging resistor
C_1 = working condenser
C_4, C_5 = voltage dividing condens = 100 pF
L = self-inductance coil
V_3 = thyratron tube
F_1, F_2 = flash tubes

---

* BARDÓCZ, Á., and KLATSMÁNYI, Á. *Rev. Sci. Instrum.*, 2 p. 945 (1955).

positive voltage signal is applied to the grid of thyratron e V_3, which is closed by a negative bias, while condenser is charged, the tube is ignited and the entire voltage of denser C_1 is applied to the terminals of F_1. Owing to s nearly double voltage tube F_1 ignites and condenser C_1 rts to discharge through F_1, R_3 and V_3. After the onset this discharge almost the entire voltage of C_1 is applied the terminals of R_3 and to those of F_2. Owing to this rly double voltage F_2 breaks down too, followed by an disturbed discharge of condenser C_1 through F_1 and F_2.

he circuit in Fig. 1 has been operated under widely varying rgy and voltage conditions. Flash tubes of breakdown tages between 2500–6000 V were used. The operating tage of V_3 was 10 kV.

Vith flash tubes of lower breakdown voltage better igniting ditions can be obtained if the circuit in Fig. 2 is used. differs from that of Fig. 1 in that it contains the voltage iding condensers C_4 and C_5 instead of resistors R_1 and R_2, and the self-inductance L instead of ohmic resistor R_3. With tubes of a breakdown voltage of about 2500 V the arrangement operates satisfactorily. With these tubes the charging voltage of condenser C_1 was 4000 V. In practice the self-inductance of the coil was 11·5 mH, the tapping at one-third of the self-inductance value.

The circuits in Figs. 1 and 2 are, of course, basic circuits, which can be supplemented by stabilizing, voltage adjusting and other elements if necessary.

The circuits have been used in illuminating a 30 cm diameter cloud chamber to a depth of 10 cm. It was found that the higher the charging voltage of condenser C_1 the better and safer the operation of the equipment. Therefore it is desirable to use the highest voltage possible and the circuit in Fig. 1.

Hungarian Academy of Sciences,
Central Research Institute for Physics,
Budapest, Hungary.

Á. BARDÓCZ
Á. KLATSMÁNYI

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

igh-vacuum, melting and pouring induction furnaces. o-Edwards Vacuum Metallurgy Ltd., Manor Royal, wley, Sussex; 161 Queens Road, Weybridge, Surrey. aflet E 180/2 describes two medium size, high-vacuum, lting and pouring induction furnaces for use in vacuum lting and casting of metals and alloys.

uide to screw thread forms. W. H. A. Robertson and Co. ., Lynton Works, Bedford. A chart entitled *The Robert- guide to screw thread forms of the world* indexes 146 series screw thread forms from twenty-one countries together h the reference numbers of relative national standards. ty external forms are illustrated.

ungsten, molybdenum and special wires. Mullard Ltd., ntury House, Shaftesbury Avenue, London, W.C.2. A der of data sheets contains a full description of a range of gsten, molybdenum and special wires. The range in- des fine wire for applications as diverse as hair lines in ical graticules to furnace elements.

ptical instruments. E. Leitz (Instruments) Ltd., 20 Mor- er Street, London, W.1. A general survey catalogue efly describes instruments for microscopy, photomigro- phy, metallography and mineralogy, also clinical apparatus, rotomes, optical-physical measuring outfits, industrial cision measuring instruments, material testing instru- nts, projection equipments of all types including a 16 mm nd film projector, prism binoculars, and the Leica minia- e camera with its range of accessories. Specialized litera- e has also been prepared.

ickel alloys by powder metallurgy. Henry Wiggin and Ltd., Wiggin Street, Birmingham 16. The application of der metallurgy to the production of wrought nickel and kel alloys has been found to offer a number of advantages npared with conventional melting methods. One of the st important is the high level of purity which can be ected. A publication, *Wiggin nickel alloys by powder allurgy*, describes the method of production and includes les of properties showing the improvements which may obtained.

Proximity meter. Fielden Electronics Ltd., Paston Road, Wythenshawe, Manchester 22. Literature describes two proximity meters, types PM 2 and PM 4. The sensitivity claimed with a probe capacity of 25 pF is 0·1 pF for full-scale deflexion on the highest sensitivity range.

Magnifiers. R. and J. Beck Ltd., 69/71 Mortimer Street, London, W.1. Magnifiers for a variety of purposes are described in a twelve-page catalogue.

Earth loop resistance tester. Evershed and Vignoles Ltd., Acton Lane Works, Chiswick, London, W.4. Publication PL 68 contains a brief description of the Megger earth loop resistance tester, series 1.

Switches and a.c.- d.c. convertor. Croydon Precision Instrument Co., 116 Windmill Road, Croydon, Surrey. Leaflet 64 describes a range of precision instrument switches. Leaflet 61 gives details of a vacuum junction type of a.c.-d.c. convertor intended for use with all types of precision d.c. potentiometers.

Eyepiece camera for photomicrography. W. Watson and Sons Ltd., 313 High Holborn, London, W.C.1. Catalogue 35611 A gives details of an eyepiece camera and accessories.

Screw gauge and profile projection lenses. J. H. Dallmeyer Ltd., Church End Works, Willesden, London, N.W.10. A range of screw gauge and profile projection lenses having recommended magnifications from ×10 to ×100 is described in leaflet D/2222/3.

High-speed, serial digit computer. Decca Radar Ltd., 1–3 Brixton Road, London, S.W.9. A brochure entitled *Decca C1 Computer* describes a high-speed, serial digit computer in which the number of electronic valves has been restricted to approximately 200 by the extensive use of magnetic cores.

Industrial radiography. Kodak Ltd., Kodak House, Kingsway, London, W.C.2. A thirty-six page booklet includes a brief account of a range of materials and equipment for industrial radiography.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impro products. The Institute of Physics assumes no responsibility for the statements given below: information for these has b taken from literature supplied.

Electronic thermometer. Headland Engineering Developments Ltd., 164–168 Westminster Bridge Road, London, S.E.1.

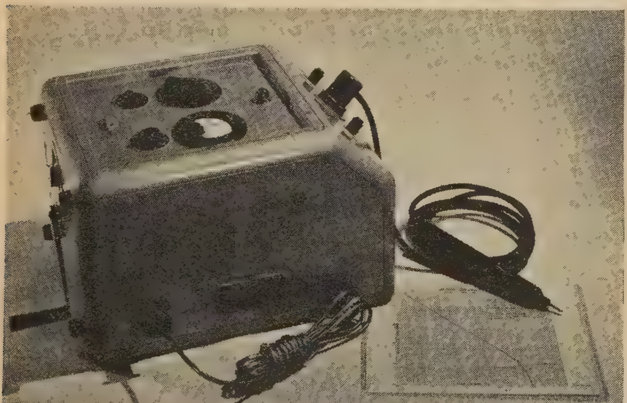
The Thermophil thermometer, manufactured by Ultrakust Geratbau of Germany, consists of a probe containing a germanium alloy, temperature-sensitive, resistance unit connected to a meter unit; extension leads of any length can be supplied. The small size of the temperature-sensitive element, which is only ¼ mm diameter, results in temperature equilibrium being attained in a few seconds. The instrument is manufactured in four ranges. For medical use the instrument is made to cover the range 25 to 45° C. For industrial use the ranges available are −10 to +110° C; −50 to +160° C; 0 to 210° C. For each range the makers claim an accuracy of approximately 1% of the whole range. The thermometer is also available with Fahrenheit scales.

Multi-circuit sequence timer. Electrical Remote Control Co. Ltd., South Road, Temple Fields, Harlow, Essex.

The type HCST timer is a heavy-duty device for controlling a continuously repeating cycle of operations; it can, however, also be arranged to stop after a cycle or part of a cycle. The timer is driven by a synchronous motor geared to a shaft with cams. Each of the cams consists of two adjustable halves; the timing of all intervals within the total timing cycle can be adjusted by turning these half-cams on the shaft. The cams operate snap-action contact piles having ¼ in. diameter silver contacts rated at 15 A (240 or 440 V) a.c. By the choice of a suitable gearing, the total timing cycle can be anything between 1 second and 30 days. It is claimed that the standard accuracy of any time interval is ½%.

Portable high-voltage unit. Lintronic Ltd., 149 Strand, London, W.C.2.

The Lintronic portable power-unit illustrated in the figure has a generator-mains-transformer combination. It is therefore self-contained, being operable either by turning a handle to drive the generator or by plugging into a.c. mains to energize the high-voltage transformer. A voltage selector switch is provided to give eleven steps of voltage from 0·5–10 kV d.c. (An alternative model covers the range 5–50 kV d.c.) The terminal voltage of the unit is stabilized to better than 1·0% against fluctuation of generator speed, and is maintained at better than 95% of its nominal value provided the curr drawn does not exceed 100 μA. Above this value, voltage falls off towards zero at a short-circuit current about 1 mA. The unit, which is intended for flash and ca testing, incorporates an output current meter read to 1 μA and a guard ring terminal. The complete u without carrying case, weighs about 29 lb and measu 14 × 10 × 9 in.



Portable high voltage d.c. unit for flash testing and cable testing

Fixed and variable voltage regulator tubes. Anton Electro Laboratories Inc., 1226 Flushing Avenue, Brooklyn New York, U.S.A.

These tubes are specially intended for the stabilization voltages from 300 V to 30 kV at currents less than a milliamps. An unusual feature of some tubes is the provis of a bellows and drive mechanism which permits variat of the gas pressure and consequently a smooth adjustment the regulated voltage. The standard model of this t covers the range 650–800 V, but tubes to cover other ran can be produced. It is claimed that both the fixed a variable voltage tubes will operate over the range of ambi temperatures − 55 to +75° C, the total change of regula voltage over this range being 1% for tubes operating bel 4 kV and less for higher voltage tubes. The tubes contain trace of radio-active material, which is stated to elimin erratic starting of the discharge.

Germanium junction diode. Mullard Ltd., Century Hou Shaftesbury Avenue, London, W.C.2.

The germanium junction diode, type OA10, combines low forward impedance of a junction rectifier with the h reverse impedance, low capacitance, and low hole storage a point-contact diode. It will pass 50 mA with a forwa voltage of 0·7 V, but less than 10 μA with a reverse volta of 20 V. The capacitance is 10 pF at a reverse voltage of 3 The diode has a rigorous hole storage specification (time tak for forward current of 10 mA to decay to 0·5 mA with inverse voltage of 7 V through 300 Ω is 0·5 μs).

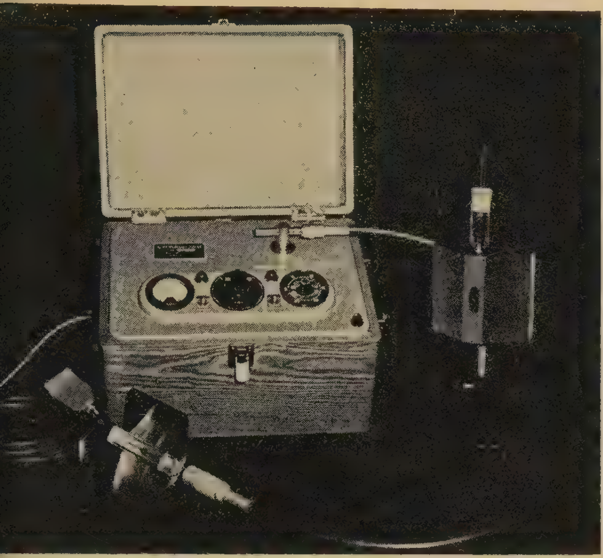
The availability of a diode with a much lower forwa impedance than a point-contact diode will enable juncti transistor computing circuits to operate from very lo voltages (e.g. 6 V), since the type OA10 diode can coup stages with a very small voltage drop.

High-fidelity delay lines. Computer Control Co., Wellesle Massachusetts, U.S.A.

The models 15 UD-1 and 30 UD-1 unit delays compr respectively 15 and 30 separate 1 μs electrical delay lin All delay lines in a unit are completely independent and c be used separately or joined in series to form any desir total delay by means of simple plugboard jumper connexion The individual delay lines are internally oriented to minimi coupling from line to line, and the whole unit is enclosed an external metal shield. It is claimed that the basic 1 delay interval is accurate to within 2%. The wave shape stated to be accurately preserved by the use of high-fideli *m*-derived lumped-constant delay lines having a 5·6 Mc cut-off frequency and characteristic impedance of 95 Both the 15- and 30-unit models are designed for standa 19 in. rack mounting and require a 10½ in. depth behind th rack. The attentuation is 1 dB per μs delay, and peak voltag up to 500 V can be used.

rcury 198 light source for optical interferometry. Baird Associates Inc., 33 University Road, Cambridge 38, Massachusetts, U.S.A.

radiation from ^{198}Hg is now recognized as the most able source for measurements by optical interferometry. Baird source, illustrated in the figure, uses a fused quartz trodeless lamp 6 mm diameter and 14 cm long utilizing ut 0·4 mg of the 198 isotope of mercury prepared by smutation of gold in an atomic pile. Argon is used as a fer to enhance the mercury excitation. The exciter is a table unit operating at a wavelength of 12·2 cm from a c/s, 115 V, a.c. mains supply. Radio-frequency energy is erated in a continuous-wave magnetron oscillator and ried in a flexible coaxial cable to the director, which centrates the radiation on the lamp. The device has a ximum power output of 125 W. The electronic circuits contained in a cabinet measuring 15 × 10 × 11 in. fitted a cooling fan.



lectrodeless discharge light source using separated 198 isotope of mercury

ger tube. Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

outstanding feature claimed for the end-window type 123 counter is the extreme thinness of its mica window 5–2·5 mg/cm^2, or 0·0002–0·000 35 in. thick). This makes tube suitable for measuring very low energy radiation, ably that emitted by ^{14}C. Another feature is the low l of background counts which in conventional lead castles tated to be 10 per min.

toelectric transducers and electronic tachometer. E.M.I. Electronics Ltd., Hayes, Middlesex.

transducers are available having as their basis a portable iature head containing a photoelectric cell and light rce designed to produce voltage pulses from reflecting faces. These reflecting surfaces may consist of bars of te paint or tape. In this way, a white paint mark on a ting body will produce from the head a voltage pulse n revolution without imposing any load on the rotating y. The output of the head is taken *via* a flexible cable a unit containing a high-gain, single-stage amplifier ether with the photocell excitation and lamp supplies.

The photoelectric head is 1 in. diameter and 3½ in. long; it is connected *via* a screened cable to the transducer unit type 1A or 1B. The former is designed for use with the E.M.I. type 3C stroboscope, the amplifier being made for internal fitting to this instrument. The type 1B transducer is a completely self-contained, mains-operated unit giving output voltage pulses of 1–5 V with the photoelectric head 1 in. distant from a rotating body with a white marker. The 1B transducer can be used in conjunction with a tachometer unit such as the E.M.I. electronic tachometer type 1A. This consists of a 4-decade counter using dekatron tubes. It is arranged to count the number of pulses, and hence the number of revolutions of the body under observation, in a period of 1, 2 or 4 s, the time being measured by an internal crystal standard. The number of revolutions is displayed for approximately 0·5 s for a 1 s count and 1 s for 2 s and 4 s counts, after which it is cleared automatically and re-counting commences at the next pulse. Alternatively, a manual setting allows the count to be made, displayed and held.

Miniature light-weight oscilloscope. E.M.I. Electronics Ltd., Hayes, Middlesex.

The model 2300 oscilloscope is a compact, general-purpose instrument measuring 4¾ × 7¼ × 7¼ in. and weighing 6¼ lb. The Y-amplifier has a sensitivity of 7 cm/V and a frequency response of 0–100 kc/s. It can be switched to give a sensitivity of 0·7 cm/V and a frequency response of 20 c/s–2·5 Mc/s. The X-amplifier has a sensitivity of 5 cm/V and a frequency range of 0–100 kc/s. The time-base covers the frequency range 7 c/s–50 kc/s and is provided with internal, external or 50 c/s synchronization.

Sound receivers and transmitters. Standard Telephones and Cables Ltd., Telephone Division, Oakleigh Road, New Southgate, London, N.11.

Sound transmitters and receivers are now available which utilize a rocking armature type of construction with a bi-polar form of symmetrical magnetic system. The transmitter and receiver capsules are similar in design and construction, the optimum characteristics for receiver and transmitter being realized by suitable minor modifications of the armature and acoustic outlet. The units are 1·83 in. in diameter and 0·65 in. thick and weigh only 1¼ oz. The receiver sensitivity is given as 46 dB relative to 1 dyn/cm^2 per square root of available power in milliwatts. The transmitter is stated to have a sensitivity, when matched at 1 kc/s to a load of 300 Ω, of 46 dB above 1 μV per dyn per cm^2 free field pressure. The frequency response is equalized within 3 dB from 200 to 3500 c/s. Within these limits, the response of the receiver is flat and that of the transmitter rises at 7 dB per octave.

Ceramic capacitors. Plessey Co. Ltd., Wood Burcote Way, Towcester, Northants.

For such purposes as r.f. decoupling, where precision of capacitance value and very low power factor are not of primary importance, ceramic capacitors of the barium titanate type are convenient because of their small size. Disk-shaped capacitors, marketed under the name Cascap are available at working voltages of 500 V d.c. or 300 V a.c. The capacitors are all approximately 0·14 in. thick and vary in diameter from 0·41 in. for the 0·001 μF size to 0·90 in. for the 0·01 μF size. The power factor varies with frequency and applied voltage, but is of the order of 1%. Another range of capacitors of similar dimensions and capacitance, but having a higher working voltage, is available for use as interference suppressors.

Notes and comments

The Institute of Physics

At the Annual General Meeting of The Institute of Physics held in London on 16 July, 1956, Mr. O. W. Humphreys (the Director of the General Electric Co. Ltd. in charge of research) was elected President, Dr. B. P. Dudding was elected a Vice-President, Dr. J. Taylor, Honorary Treasurer and Professor F. A. Vick, Honorary Secretary. The two new Ordinary Members of the Board elected were Dr. L. R. G. Treloar and Mr. G. W. Warren. Sir George Paget Thomson was elected to Honorary Fellowship in recognition of his contributions to physics and his services to physicists.

The Report for 1955, which was adopted at the meeting, shows that during the year the total membership passed 5000; 726 applications for election or transfer to the various grades were considered compared with 579 the previous year. Representatives of the Institute visited seven technical colleges, which had applied for recognition or a continuance of recognition by the Institute. The Institute's recently established Graduateship examination was taken in four centres by 54 candidates of whom only 11 satisfied the examiners. The number of candidates for the final examination for National Certificates in Applied Physics was 309 at the Ordinary level and 82 for the Higher Certificate. These figures compare with 206 and 75 respectively in 1954. The Board has continued to comment upon and support proposals for the development of facilities for higher technical education. It accepted an invitation from the Ministry of Education to nominate a member to one of the two Boards of Studies set up to advise the newly appointed National Council for Diplomas in Technology. Arising from concern felt at the increasing evidence of declining numbers of advanced students in the physics departments of several well-equipped technical colleges, the Board decided to institute an inquiry into the availability of places for students of physics in the universities and larger technical colleges of the country. A report on the findings was published and comments on it were made in the scientific and technical press.

The Report records the continued increase in circulation of both the *Journal of Scientific Instruments* and the *British Journal of Applied Physics*, the fourth Supplement of which was devoted to the proceedings of a conference on "Luminescence with particular reference to solid inorganic phosphors."

Two volumes in the "Physics in Industry" series were published during the year. They were the ¼-million-word book entitled *X-ray Diffraction by Polycrystalline Materials* to which 31 members of the Institute's X-ray Analysis Group contributed. The other volume was entitled *Physics of Fibres*. Three small books were added to the "Student Monograph" series, namely *Theory of Lenses*, *Humidity* and *Errors of Observation and their Treatment*.

The sentence in the Report, "The permanent Officers have again dealt with a regular flow of inquiries on professional matters and the Board expresses its thanks to the several Fellows who have assisted them with expert advice," is modest record of work of a confidential nature carried o towards the "elevation of the profession of physicist" wh is one of the Institute's objects. Another activity on beh of physicists and their dependents, referred to in the Repo is the Benevolent Fund.

The Institute was one of the constituent bodies which duri the year founded the (permanent) British Nuclear Ener Conference; the Board welcomed this opportunity of furth collaboration with the engineering institutions.

Nearly one hundred meetings were held during the year the Institute's Branches and specialist Groups in the Unit Kingdom, among which was the inaugural meeting of t Liverpool and North Wales Branch. Some of the meetin took the form of two- or three-day conferences. T Australian Branch staged an exhibition of scientific instr ments and apparatus in Sydney in November, and he several meetings.

As usual the brief reports from the Institute's representativ on outside bodies demonstrate the wide interests and ma activities with which the Institute is associated.

Symposium on magnetic resonance

A symposium on magnetic resonance is being arranged the Liverpool and North Wales Branch of The Institute Physics at the University College of North Wales, Bango on 26 and 27 September, 1956. Lectures will be given Dr. B. Bleaney (Clarendon Laboratory, University of Oxfor on free atom resonance, Dr. J. G. Powles (Queen Ma College, London) on spin echo techniques, Dr. R. E. Richar (Department of Physical Chemistry, University of Oxfor on magnets, and Professor E. R. Andrew (University Colle of North Wales, Bangor) on nuclear magnetic resonan work and other research at Bangor.

The formation of a subject group to provide occasion meetings will be considered at this symposium.

Further particulars of the symposium may be obtain from Professor E. R. Andrew, Physics Department, Univers College of North Wales, Bangor, Caernarvonshire. Acco modation will be available for a limited number in the H of Residence for Men Students.

British Journal of Applied Physics

Contents of the August issue

SPECIAL ARTICLE

Physics in oceanography. By K. F. Bowden.

ORIGINAL CONTRIBUTIONS

Dielectric properties of polar solutes in non-polar solvents at microw frequencies. By D. E. Clark and S. N. Kumar.
The expansion of mercury and fused silica between 0 and 300° C. By A. H. Co
The tension in strings wrapped slantwise round cylinders when friction is p portional to a power of the normal reaction. By C. Mack.
Space-charge limited current in insulating oil. By Tadashi Satō, Shigeo Nag and Yotsuo Toriyama.
The vibration of segmented beams. By J. P. Ellington.
Applications of a transformer analogue computer. By J. R. Barker.

NOTES AND NEWS

Correspondence
New books
Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 10*s*. each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

ORIGINAL CONTRIBUTIONS

A portable temperature-chlorinity bridge for estuarine investigations and sea water analysis

By B. V. Hamon, B.Sc., B.E., Division of Electrotechnology, National Standards Laboratory, Commonwealth Scientific and Industrial Research Organization, Australia

[*Paper received* 30 *April*, 1956]

An instrument for the measurement of temperature and chlorinity of water *in situ* is described. A thermistor is used for temperature measurement, and an electrical conductivity cell, the temperature coefficient of which is compensated by means of the thermistor, is used for chlorinity. The instrument is direct reading, with ranges of 0–30° C for temperature and 0–16 p.p.t. (parts per thousand) and 16–20 p.p.t. for chlorinity. The accuracy is ±0·1° C for temperature, and ±0·05 p.p.t. for chlorinity on the higher range. When used in the laboratory as a transfer instrument, an accuracy of ±0·02 p.p.t. in chlorinity can be obtained.

ydrologic studies in estuaries require the measurement of mperature and chlorinity* at different positions and depths. ince a large number of measurements must be made, it is n advantage to be able to make them *in situ*, instead of ollecting samples for laboratory analysis. Temperature neasurements present little difficulty, but although a number f instruments have been designed for chlorinity measurement, they have not been extensively used. This paper escribes a portable direct-reading instrument for the neasurement of temperature and chlorinity. Although the nstrument was developed specifically for field measurements n estuaries, it has also been used extensively in the laboratory or determining the chlorinity of sea water samples. It has een found capable of an accuracy of ±0·02 p.p.t. under hese conditions, and is very convenient and rapid to use.

The instrument consists of a measuring head (Fig. 1) which s lowered into the water, and a shipboard unit containing the ridge circuits, oscillator, detector and batteries. The neasuring head is connected to the shipboard unit by 80 ft f twin-core shielded microphone cable. For field use a 1 lb ead weight is suspended by means of a cord 3 ft below the neasuring head. Since the cable stress is small, a separate upporting cable is not required. Depth is indicated by narks on the cable, and the measuring head is held at each lepth until readings of temperature and chlorinity have been btained by manual balancing of the bridge circuits. The quipment is operated by dry batteries, and is suitable for se in an open boat.

The equipment uses a "thermistor" (negative—temperature—coefficient resistor) as the temperature measuring lement, and a conductivity cell for the measurement of hlorinity. The long-term stability of thermistors is still not vell known, and may vary according to type and maker. They were chosen for this instrument partly because of their onvenience and small size, but mainly because their use ermits a simple and accurate temperature compensation of he conductivity cell. The general design provides for interchangeable measuring heads, so that if a thermistor or cell ecomes defective, the head can be replaced without changing he direct-reading scales of the instrument. Frequent checks gainst mercury thermometers and standardized sea water are made, and any small changes found are applied as corrections to the instrument reading.

The chlorinity circuit is provided with two ranges, 0–16 p.p.t. and 16–20 p.p.t. The 16–20 p.p.t. range is subdivided to 0·05 p.p.t. and can be read to ±0·01 p.p.t. A single temperature range of 0–30° C is provided. It is subdivided to 0·2° C and can be read to ±0·05° C.

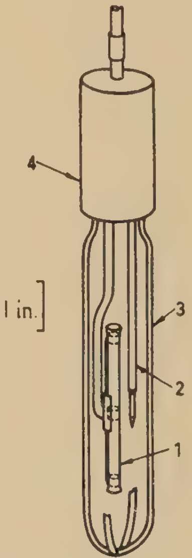


Fig. 1. Measuring head

(1) conductivity cell attached to metal support; (2) thermistor; (3) guard; (4) epoxy resin casting.

MEASUREMENT OF CHLORINITY

Of the properties of sea water that depend on chlorinity, electrical conductivity is the most easily adapted to *in situ* measurements. It has been used for this purpose by a number of workers.(1–4) The two main difficulties in using conductivity are polarization of the electrodes, and the large variation of conductivity with temperature.

Polarization is an electrode surface effect, and can be considered as an additional resistance and capacitance in series with the cell. Only the resistance need be considered in the present case. The additional polarization resistance depends on many factors, including the cleanliness of the

---

* Chlorinity (Cl) is defined by the equation

$$Cl = (S - 0\cdot03)/1\cdot805$$

here S is the salinity, or concentration of salt in parts per thousand .p.t.) by weight. The average chlorinity of sea water is about 9·5 p.p.t.

electrode surfaces, and can be expected to change with time. It will be seen that unless the polarization resistance is small in comparison with the total cell resistance the results obtained will not be reliable. The ratio of polarization resistance to cell resistance depends on cell geometry, electrode material, frequency, temperature and conductivity.(5–7) For laboratory studies of electrolytic conductivity, the classical method of reducing the effect of polarization has been to use "platinized" platinum electrodes (electrodes coated with a layer of finely divided platinum deposited electrolytically), and to use a frequency of at least 1000 c/s. When the greatest accuracy is required, the platinized electrodes must be very carefully treated; they must be kept wet at all times, must not be touched, and must be kept free from oil or grease and from organic contamination. These requirements have restricted their use in field instruments. However, the fractional accuracy required for chlorinity measurements (about 0·1%) is an order of magnitude less than can be achieved in laboratory conductivity studies, and it appears that the above requirements can be relaxed for this application. The advantages of platinization are so great that it was decided to use the method in the present instrument. The disadvantages can be reduced by providing interchangeable measuring heads, by re-platinizing the electrodes at regular intervals, and by frequent checking against standardized sea water.

The platinum electrodes of the conductivity cell are fused to the inner wall of a glass tube 3 in. long and 0·25 in. internal diameter. The two outer electrodes are connected together so that the electric current flows through the two halves of the cell in parallel. The cell constant is 4·4 cm^{-1}, giving a resistance of approximately 100 Ω in water of chlorinity 20 p.p.t. at 15° C. Under these conditions the polarization resistance at the frequency of the oscillator (3000 c/s) was found to be approximately 0·05% of the cell resistance, when measured by the frequency-change method of Jones and Bollinger.(6) This is equivalent to 0·01 p.p.t. in chlorinity. The polarization resistance could be further reduced by using a longer cell or decreasing its bore, or by using a higher frequency, but it is considered that the above conditions represent a reasonable compromise. A change in the cell dimensions may lead to flushing difficulties, or to a cell of awkward length. The improvement gained by using a higher frequency is proportional only to the square root of the frequency, while the effects of capacitance unbalance on the bridge detector become more serious in direct proportion to the frequency.

It is found that the polarization resistance increases with time while the cell is immersed in sea water. The resistance returns to its original value after immersing the cell for a minute or two in dilute hydrochloric acid. Immersion in acid has also been found advisable before putting the cell into use again after it has been allowed to dry.

TEMPERATURE COMPENSATION

An instrument reading directly in chlorinity units can be obtained either by using a servo-system to compute chlorinity from measured values of temperature and conductivity,(1) or by compensating the effects of temperature.(4) The computing servo-system is difficult to design and adjust, and is not suitable for use in field equipment where size and weight should be kept to a minimum. Compensation for temperature is most easily obtained by using a temperature-sensitive resistor placed close to the conductivity cell, and connected in one of the arms of the bridge in which the resistance of the cell is measured. The use of a thermistor as the temperat sensitive resistor has been discussed by Dorrestein(4) an similar circuit is used in the present instrument.

A simplified diagram of the chlorinity bridge is show Fig. 2. The thermistor T has a fixed resistor R_2 in series it. The value of R_2 is chosen so that the temperat coefficient of the bridge arm formed by T and R_2 in se is as nearly as possible equal to that of the conductivity in the adjacent arm, when immersed in water of ab 19·5 p.p.t. chlorinity. As Dorrestein(4) has pointed out, adjustment will also hold with acceptable accuracy for wa of different chlorinity, so that the balancing arm P can calibrated directly in chlorinity units.

The resistance ratios of the cell and thermistor arms of bridge shown in Fig. 2 may be made the same at any chosen temperatures by suitable choice of R_2. The value the ratio for other temperatures in the required temperatu range then depends on the properties of the particular ty of thermistor used, and it is only by chance that for mo

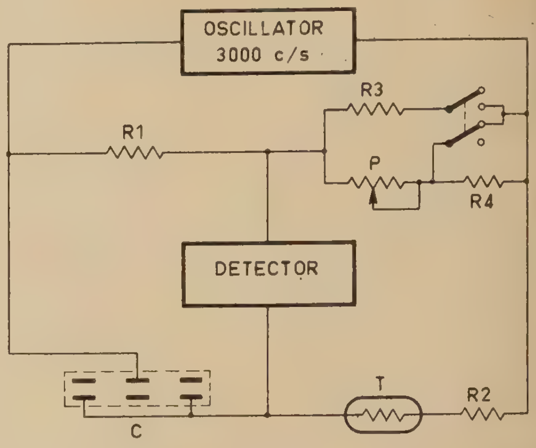


Fig. 2. Simplified circuit diagram of the chlorinity bridge

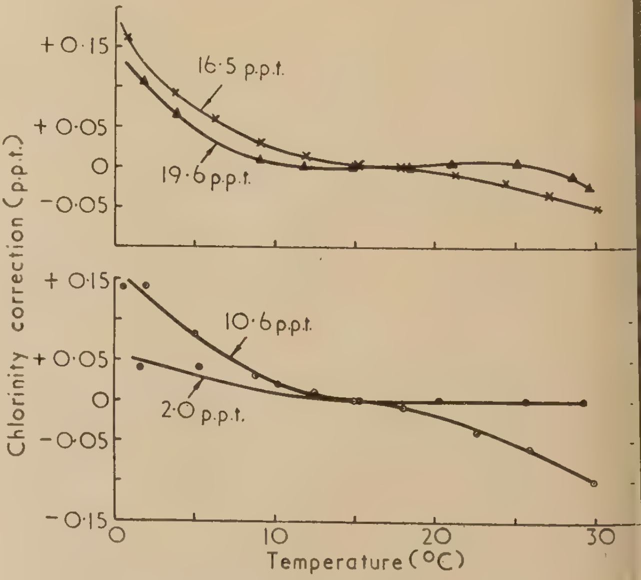


Fig. 3. Chlorinity dial corrections as a function of temperature for four different chlorinities

mistors the ratio is very nearly constant for the tempera- range 0–30° C.(4) Exact equality of the ratio at any e chosen temperatures can be obtained by connecting ther resistor in parallel with either the thermistor arm or cell, and a more nearly constant ratio throughout the perature range can be obtained in this way. Equations calculating the fixed resistors when the thermistor perature law and cell constant are known have been ved, and are given in the Appendix. These equations e been used with type F thermistors (made by Standard ephones and Cables Ltd.). They show that the additional stance should be in parallel with the thermistor arm for e F 2311 thermistors, and in parallel with the cell for type 200 thermistors. The latter type is used in the present rument, but the additional fixed resistor has not been uded as its effect is relatively small. It could be used in case only on the 16–20 p.p.t. chlorinity range (see pendix). Fig. 3 illustrates the degree of temperature npensation that can be achieved with the circuit of Fig. 2. hows typical corrections to the reading of the chlorinity as a function of temperature for chlorinities of 19·6, 5, 10·6 and 2·0 p.p.t., on the assumption that the dial correctly scaled at a temperature of 15° C.

TEMPERATURE MEASUREMENT

he temperature measuring circuit is straightforward. The e thermistor is used, the conductivity cell being replaced a fixed resistor. The resistor R_2 of Fig. 2 is left in series n the thermistor, so that the temperature-sensitive arm he bridge will have very nearly the same relative resistance es for different thermistors.

COMPLETE INSTRUMENT

Fig. 4 is a circuit diagram of the complete instrument. The oscillator is tuned to approximately 3000 c/s by the capacitor in parallel with the output transformer. The latter is designed to deliver not more than 0·5 V r.m.s. to the bridge, as a greater supply voltage heats the thermistor and makes its resistance dependent on the rate of flow of water, and on the supply voltage.

The detector amplifier has a tuned input transformer (turns ratio 100/1) followed by a single tetrode stage and a phase-sensitive detector (see e.g. Hague,(8) p. 244). The use of a phase-sensitive detector allows the bridge to be balanced by operating only one control, as the detector is not sensitive to signals due to capacitive unbalance, provided these signals are not too large. Almost all capacitance across bridge arms is due to the cable. The capacitance can be balanced out approximately for the mean readings of the 16–20 p.p.t. chlorinity range and the temperature range by selecting suitable values for capacitors C_1 and C_2 respectively. Resistors R_9 and R_{10} of Fig. 4 reduce the detector sensitivity on the temperature range and on the 0–16 p.p.t. chlorinity range.

Three of the resistors in the bridge circuit (R_6, R_7, R_8, Fig. 4) are mounted in the socket attached to one end of the cable. These resistors are adjusted to slightly different values for each measuring head, so that the direct-reading scales attached to P_1 and P_2 can be used for all heads. When a new measuring head is made up, R_8 is first chosen to give the best temperature compensation for the particular thermistor used in the head. Resistors R_6 and R_7 are then adjusted so that the chlorinity and temperature dials, respectively, are correct at any convenient setting. When

R_1 = 250 Ω, w.w.
R_2 = 350 Ω, w.w.
R_3 = 100 Ω
R_4 = 440 Ω, w.w. (approx.)
R_5 = 580 Ω, w.w. (approx.)
R_6 = 80 Ω, w.w. (approx.)
R_7 = 400 Ω, w.w. (approx.)
R_8 = 100 Ω, w.w. (approx.)
R_9 = 300 Ω
R_{10} = 50 Ω
R_{11} = 75 kΩ
R_{12} = 100 kΩ
R_{13} = 1 MΩ
R_{14} = 1 kΩ
R_{15} = 5 kΩ
R_{16}, R_{17} = 100 kΩ
R_{18} = 25 kΩ
R_{19} = 500 kΩ

P_1 = 250 Ω (0–30° C)
P_2 = 250 Ω (chlorinity)

C_1 = 0·006 µF
C_2 = 0·003 µF
C_3 = 60 pF (approx.)
C_4 = 100 µF
C_5, C_6 = 0·1 µF
C_7 = 0·001 µF
C_8, C_9 = 0·1 µF

V_1–V_4 = DL66

M = 50–0–50 µA

Switch positions

$S1a$–$S1c$ = { 1, chlorinity; 2, temperature
$S2a$–$S2d$ = { 1, 0–16 chlorinity; 2, 16–20 chlorinity

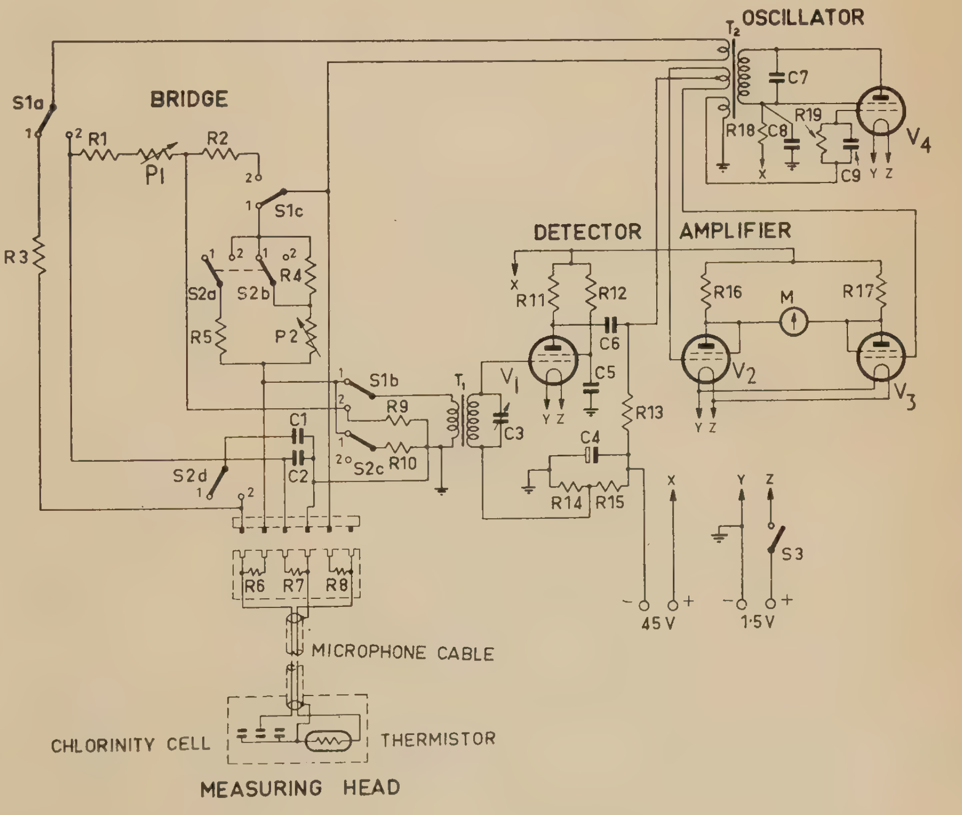


Fig. 4. Circuit diagram of the temperature-chlorinity bridge

this has been done, the design of the bridge circuits ensures that the dials will be correct at all other settings. In principle, differences in the shape of the thermistor temperature characteristic will affect the degree of temperature compensation attainable, and thereby affect the accuracy of the direct-reading scales, but in practice the errors from this source are negligible.

OPERATING EXPERIENCE

Most of the operating experience has been gained with a prototype instrument that differed in several minor respects from the circuit shown in Fig. 4, although the conductivity cells and method of temperature compensation were the same. A frequency of 1000 c/s was used in the prototype instrument.

In the measurement of temperature, an accuracy of ±0·1° C can be achieved and maintained over periods of at least several months. In this connexion, the results of some laboratory tests on a number of thermistors are of interest. Twenty type F 2311 and twelve type F 2200 thermistors were measured, at a fixed temperature, several times during a period of three months. When being measured, the thermistors were immersed in a mixture of crushed ice and water in a vacuum flask. Two thermistors changed by the equivalent of 0·1° C and two others by 0·04° C in this time. The remaining twenty-eight thermistors showed changes of less than 0·03° C. These tests suggest the advisability of selecting thermistors on the basis of measured stability, and this practice is now being followed. Further information on the stability of type F 2311 thermistors is given by Mortimer and Moore(9) and Beck.(10)

The accuracy of chlorinity measurement is more difficult to specify, and depends more on the conditions of use. With the prototype instrument, the conductivity cell was kept in water when not in use. Sea water and distilled water were used at different times. Sea water was found unsatisfactory, owing to corrosion of metal parts of the measuring head, deposition of carbonate on the cell and growth of bacterial slime. Distilled water is more satisfactory, but needs to be changed frequently to avoid contamination and subsequent organic growth. Recently the cell has been rinsed and allowed to dry when not in use, and rinsed with dilute hydrochloric acid just before re-using. This treatment appears to be satisfactory, although a slight change in the chlorinity reading can be detected during the first few minutes' use. In the laboratory, where most of the work with the prototype instrument has been done, a check reading on water of known chlorinity is taken after every five measurements on "unknown" samples. Thus the instrument is used only as a transfer instrument, and, provided the known and unknown are at nearly the same temperature, even the errors due to lack of exact temperature compensation can be neglected. When used in this way to measure differences in chlorinity between known and unknown samples, an accuracy equivalent to that of the usual titration method (±0·02 p.p.t.) is regularly obtained. Samples can be handled at the rate of thirty an hour, and the same samples can be used afterwards for other tests.

In the field a similar transfer technique can be used, but in general it will not be possible to ensure temperature equality between the known sample and the unknown. In this case the measurement on the known sample gives a correction at the temperature of the known sample, and an additional correction, depending on the measured chlorinity and temperature at each depth, must be applied. An accuracy of about ±0·05 p.p.t. can be obtained under these conditions.

The frequent measurements on known samples quic
reveal any change in the electrodes and indicate when repla
izing is necessary. It has been found necessary to replati
the electrodes after about three months, but this is based
the practice of keeping the electrodes wet when not in
On one occasion, after some months' use, the polarizatio
3000 c/s was found to be about 1% of the cell resistan
compared with 0·05% for a recently platinized cell. T
had produced a chlorinity error of 0·2 p.p.t. at the hig
chlorinities.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of
N. L. Brown in the design and calibration of the instrume
and of members of the staff of the Division of Fisheries
Oceanography, C.S.I.R.O., in field and laboratory tests.

REFERENCES

(1) Jacobsen, A. W. *Trans Amer. Instn Elect. Engrs*, **67**
p. 714 (1948).
(2) McCourt, C. F. *J. Sci. Instrum.*, **30**, p. 241 (1953)
(3) Wattenberg, H., and Joseph, J. *Ann. Hydr. Mar. M*
71, p. 240 (1943).
(4) Dorrestein, R. R. *Kon. Nederlands Meteor. Inst. Me*
Verhand., No. 59, p. 387 (1954).
(5) Jones, G., and Christian, S. M. *J. Amer. Chem. Sc*
57, p. 272 (1935).
(6) Jones, G., and Bollinger, D. M. *J. Amer. Chem. Sc*
57, p. 280 (1935).
(7) Einstein, P. A. *Brit. J. Appl. Phys.*, **2**, p. 49 (1951).
(8) Hague, B. *Alternating Current Bridge Methods,*
ed. (London: Sir I. Pitman and Sons Ltd., 1945).
(9) Mortimer, C. H., and Moore, W. H. *Internatio*
Association of Theoretical and Applied Limnolo
Communications No. 2 (Stuttgart, 1953).
(10) Beck, A. *J. Sci. Instrum.*, **33**, p. 16 (1956).

APPENDIX

Equations for temperature compensation

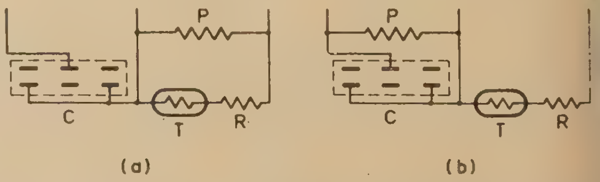
The two compensation circuits are shown in Figs. 5(*a*) a
(*b*).

Let subscripts 1, 2 and 3 refer to the three temperatures
which the ratios of the two arms of the bridge are to be ma
equal.

$$\text{Let}\quad p = P/T_2 \text{ [Fig. 5(}a\text{)]} \quad \text{or} \quad = P/C_2 \text{ [Fig. 5(}b\text{)]}$$
$$r = R/T_2 \quad x_1 = C_1/C_2 \quad x_3 = C_3/C_2$$
$$y_1 = T_1/T_2 \quad y_3 = T_3/T_2$$

Then for both Figs. 5(*a*) (*b*)

$$r = \frac{y_1 y_3(x_3 - x_1) - x_1 x_3(y_3 - y_1) + x_1 y_3 - x_3 y_1}{x_1 x_3(y_3 - y_1) + x_1 y_1 - x_3 y_3 + x_3 - x_1}$$



(a) (b)

Fig. 5. Alternative temperature compensation circuits

e for Fig. 5(*a*)

$$p = \frac{(x_1 - 1)(r + y_1)(1 + r)}{(y_1 - x_1) - r(x_1 - 1)}$$

for Fig. 5(*b*)

$$p = \frac{x_1(y_1 - 1)}{r(x_1 - 1) - (y_1 - x_1)}$$

will be noticed that the two expressions for p are of osite sign, since the numerators are both positive if $< T_2$.

Thus either Figs. 5(*a*) or (*b*) should be used according as $(y_1 - x_1)$ is greater than or less than $r(x_1 - 1)$.

When p is omitted, as in Fig. 2, the equation for r is

$$r = (y_1 - x_1)/(x_1 - 1)$$

where x_1 and y_1 are defined as above, and subscripts 1 and 2 refer to the two temperatures at which equality of ratio is desired.

The circuit of Fig. 5(*b*) is restricted to applications in which the chlorinity range is small, since P depends on the value of C at a particular temperature, and this in turn depends on chlorinity.

The measurement of film thickness with a pneumatic hypodermic needle mechanism

By N. Stolow, B.Sc., M.A., Ph.D., Courtauld Institute of Art, University of London, London, W.1

[*Paper received* 30 *April*, 1956]

An apparatus is described by means of which the measurement of film thickness may be made on supported polymer films in a non-destructive manner. This apparatus is based on the principle of flow of a gas, e.g. nitrogen, through the space formed by the tip of a cut-off hypodermic needle and a given surface. The theory, an extension of a previous one for a swelling measurement apparatus, is presented and appropriate sensitivity expressions are derived. Agreement with the theory is good except when the rate of flow parameter is high, and kinetic energy corrections must then be applied. The r.m.s. error in the location, at a fixed distance away, of a point on a surface is found to be $\pm 0 \cdot 2\ \mu$. The films are ordinarily cast on optically selected flat-faced glass plates which are mounted on the flat base plate of the apparatus. By lateral sliding action of the support on the base plate, a number of surface locations are made on the film and around the film edge from which the mean film thickness is obtained. The r.m.s. error in the mean film thickness is found to be $\pm 0 \cdot 4\ \mu$ for films ranging from 10 μ to greater than 200 μ in film thickness.

the course of research on some of the physical and chemical perties of glass-supported polymeric films it was necessary gauge film thickness accurately in a non-destructive nner. In particular it was desirable to measure the thicks of such films, 10 μ or greater, to within $\pm 0 \cdot 5\ \mu$.

On reviewing the literature relating to the measurement of thickness it was found that most methods were either tructive to the film or required metallic supports. Thus in micrometer dial gauge method described by Gardner and ard(1) the location of the support surface necessitates the noval of film. Additional difficulty is experienced in such chanical probing methods arising from the compressibility many polymeric film materials. To some extent these iculties are overcome in the methods of Spilsbury(2) and New Jersey Zinc Co. (described on p. 147 of Ref. 1), ere vibrating reeds or optical devices are applied. arendon(3) in a review describes several modern electrical magnetic metering methods in which the substrates are trically conducting or magnetically permeable. In general accuracy of such methods is seldom better than $\pm 0 \cdot 5\ \mu$, little information is given regarding the variation of film kness over small areas.

n this paper is described an apparatus in which some of shortcomings of the above methods are overcome. The nique of measurement of film thickness, in addition, is tively simple to apply.

THE HYPODERMIC NEEDLE MECHANISM AND THE GAS FLOW SYSTEM

The instrument shown in Fig. 1 consists essentially of a stand and focusing mechanism of a good grade Leitz microscope, to which is attached a hypodermic needle N, the end of which is cut off accurately at 90°. (This operation was carried out with a special jig on a metal-cutting lathe.) The adjustment of the needle at right angles to the lower surface is made with the ball-and-socket joint J. In order to raise or lower the needle relative to the lower surface, the film F, a coarse adjustment knob K, or a fine adjustment knob positioned further down, is used. The operation and calibration of the focusing mechanism has already been described by the author.(4) One division of the circular scale was found to correspond to a vertical displacement of very nearly 1 μ, while the smallest displacement measurable on the scale corresponded to approximately $0 \cdot 2\ \mu$.

Fixed to the stage of the instrument, by means of Canada balsam, is an optically flat glass plate P which has a drilled hole through which suction, as at S, may be applied. In this way glass-supported films may be held rigidly in place on the apparatus.

The gas flow system is represented schematically in Fig. 2. An inert gas, e.g. nitrogen, is passed from a cylinder through an immersed constant head device consisting of a T-tube and a gas storage bottle. The maximum pressure head is controlled by the depth of immersion of the T-tube in the water, while fluctuations in gas pressure are smoothed out effectively by the gas storage bottle. The flow of gas is controlled by a fine needle valve *N.V.*, and the rate of flow is measured from a calibrated flow meter of conventional design. Finally the pressure in the system, where the gas just enters the hypodermic needle, is recorded on the water manometer.

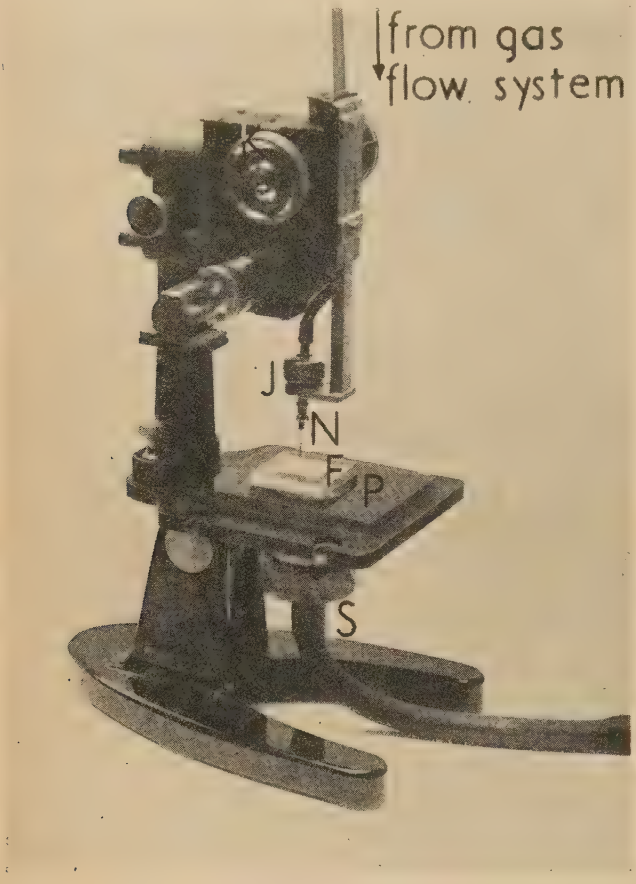


Fig. 1. The hypodermic needle mechanism for the measurement of film thickness

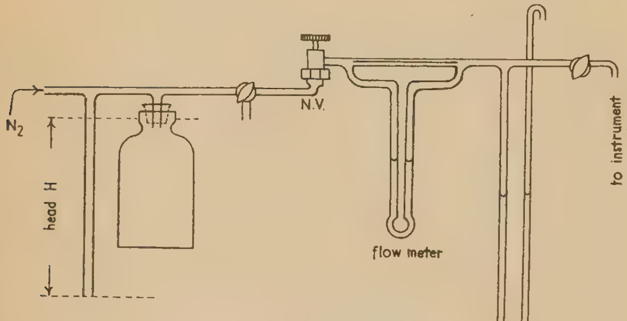


Fig. 2. Nitrogen gas flow system with flowmeter and manometer

THE MEASUREMENT OF FILM THICKNESS

For a given pressure head, H cm of water, and for a given rate of flow, Q cm^3/s, the observed manometer pressure will be of some value $H' < H$. If the separation, h cm, of the ne tip from the surface to be probed is very large, e.g. at infi then the observed rate of flow will be at some maximum va Q_0 cm^3/s, while H' will be at some minimum value, H'_0. general the term Q_0, the rate of flow parameter, depends the given setting of the needle valve and on the pressure h H. If the flow of gas through the needle is restricted, e.g. reducing h, then the rate of flow will also be reduced, t value less than Q_0. At the same time the manometer press H' will be increased, and will tend to approach H. significant relationship between h and H' is discussed in section "Theory of the Apparatus."

Some preliminary experiments were carried out with hypodermic needle mechanism (Fig. 1) in order to determ the root mean square error for the location of a fixed p on a surface at a distance h. For this purpose a flat g plate $1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{4}$ in. was mounted on the stage of apparatus and was held down by suction. The hypoder needle that was used was British wire gauge 22 (B), and values of Q_0 and H were respectively $0{\cdot}80$ cm^3/s, and 42·3 of water at 19° C. The dimensions of the hypodermic nee were as follows: inner diameter, $0{\cdot}041 \pm 0{\cdot}0004$ cm; ou diameter, $0{\cdot}052 \pm 0{\cdot}0015$ cm; length, 1·98 cm. The nee was lowered and raised repeatedly; each time the same va of $H' = 31{\cdot}4$ cm of water being attained. The correspond reading of the scale was noted, giving the separation of needle tip from the plate. From fifty such surface locati it was found that the root mean square error did not amo to more than $\pm 0{\cdot}2\ \mu$ from the true value of h.

In the measurement of film thickness it is necessary gauge or locate not only the film surface but also that of substrate or support. The films tested were cast on squa of optically selected plate glass, $1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{4}$ in., with edges bevelled and polished. When such plates were moun on the apparatus, as at *F* in Fig. 1, an indication of intimacy of contact with the base plate *P* would be given the appearance of characteristic fringe patterns. Usually was not necessary to apply suction to secure the plate film. The closeness of contact between the glass surfaces such that sticking occurred. If a slight lateral pressure w now applied, the glass plate could slide about with very lit friction, and at the same time the optical fringe pattern wou not be appreciably disturbed. Since the method of measu ment of film thickness depends on the sliding action of t glass plates, it was considered necessary to investigate t nature of any errors arising from this.

A circular optical flat, $2\frac{1}{2}$ in. in diameter, was placed on t apparatus and by causing it to slide about, a number surface points separated by approximately 5 mm we gauged by the hypodermic needle mechanism. Again t values of Q_0, H and H' were set to certain values. repeatedly sliding the plate twenty times it was found that t root mean square error did not amount to more than $\pm 0{\cdot}3$ in h for a given point on the surface of the optical flat. T proved that, provided the applied glass plate is in good optic contact with the base plate, and provided that the slidi action is effected by slight lateral pressure, the reproducibili in the location of surface points could be very high. As rule the sliding did not produce larger errors than $\pm 0{\cdot}3$ in h, so long as the optical fringe pattern remained unchange

Consider the arrangement of the film and plate as Fig. 3(*a*). Suppose that the two glass surfaces are in goo optical contact as shown by the appearance of a broad frin pattern. The hypodermic needle is in a fixed positi throughout, but can be raised or lowered when necessary. is possible to locate first the substrate surface at *A*, and the gentle sliding of the plate (in the direction indicated), to ate the surface of the film at some point *B*. If the thickness the substrate has not changed over the interval *A–B*, then thickness of the film at *B* would be simply the difference the scale readings of the instrument corresponding to *A* 1 *B*. If, on the other hand, the substrate plate has anti-rallel but plane surfaces, then it is still possible to measure film thickness at *B*, but additional information must be d on the variation of the thickness of the substrate over interval *A–B*.

For the film thickness measurements eight points (*A*, . . . *H*) were probed on the glass surface around the edge the film and nine points (1, 2, . . . 9) were probed over the n surface. The relative positions of these points are shown the plan view of a typical film [Fig. 3(*b*)]. The different ations were carried out by gentle sliding of the glass plate, ing care not to disturb the optical fringe pattern. As ıal, Q_0 and *H* were fixed to suitable values, and the needle s lowered until the manometer registered a given value of . This value was chosen to correspond to maximum ısitivity, i.e. when $H' = \frac{2}{3}(H + H_0')$. Some sample film ckness determinations are recorded in Table 1.

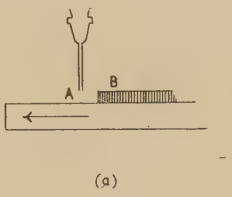
Table 1. *Measurement of film thickness of several films*

$= 0{\cdot}82\ \text{cm}^3/\text{s}$, $H = 37{\cdot}0$ cm water, $H' = 26{\cdot}0$ cm water, hypodermic needle B.w.g. 22 (B)

ilm description		*Glass surface locations revolutions*	*(µ)*		*Film surface locations revolutions*	*(µ)*	*Film thickness (µ)*
dried linseed oil	*A*	164	47·0	1	164	35·5	
	B	164	46·9	2	164	34·6	
	C	164	46·8	3	164	35·8	
	D	164	46·5	4	164	35·6	
	E	164	46·9	5	164	35·2	
	F	164	47·0	6	164	34·4	
	G	164	47·1	7	164	35·6	
	H	164	47·0	8	164	35·0	
				9	164	35·0	
mean:		164	46·9		164	35·2	11·7 (±0·6)*
Sellotape	*A*	164	60·8	1	163	85·3	
	B	164	60·8	2	163	87·2	
	C	164	60·6	3	163	85·6	
	D	164	60·4	4	163	85·4	
	E	164	60·4	5	163	84·7	
	F	164	60·6	6	163	85·3	
	G	164	61·3	7	163	86·4	
	H	164	61·5	8	163	85·1	
				9	163	85·5	
mean:		164	60·8		163	85·6	75·2 (±1)
) white lead paint	*A*	164	25·3	1	162	59·5	
	B	164	25·6	2	162	56·9	
	C	164	28·1	3	162	56·0	
	D	164	27·8	4	162	57·3	
	E	164	24·1	5	162	57·0	
	F	164	23·8	6	162	56·5	
	G	164	21·5	7	162	58·8	
	H	164	21·8	8	162	57·5	
				9	162	58·2	
mean:		164	24·8		162	57·5	167·3 (±2)

* The figures in brackets indicate the range in film thickness out the mean value.

order to obtain the film thickness the location values for e glass and film surfaces are averaged as in Table 1, and e difference of the means gives the film thickness averaged ver the measured surface. It appears at first dubious that ne should apply the mean value for the glass surface locations in order to arrive at the film thickness. It may be shown that with glass plates, the surfaces of which are either parallel or slightly inclined to one another, the above procedure is valid. The average of the glass positions *A* . . . *H* measured then corresponds to the locations on the glass plate immediately underneath the film surface. This has been confirmed in a large number of cases. Where this procedure did not apply it was found that the glass plate had convex or concave surfaces and therefore the mean of the glass positions *A* . . . *H* would not correspond to the location of the glass surface immediately underneath the film. Such glass plates were not used for the casting of films.



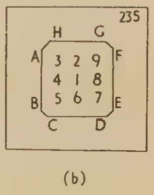


Fig. 3. (*a*) Side view of supported film during thickness measurement. (*b*) Plan view of typical film showing the various surface points located for thickness measurement

Some additional experiments were carried out to determine the reproducibility in the measurement of film thickness of a given film and typical results for films of differing thicknesses are given in Table 2.

Table 2. *Reproducibility in film thickness measurement*

Film No.	*Mean film thickness (µ)*	*Film No.*	*Mean film thickness (µ)*
1	11·7 (±0·6)*	214	24·5 (±2)
1	11·6 (±0·6)	214	24·6 (±2)
1	11·5 (±0·8)	214	24·4 (±2)
1	11·6 (±0·7)	214	24·7 (±2)
r.m.s.	11·6 ± 0·1 (±0·7)†		24·6 ± 0·2 (±2)
321	73·6 (±1·0)	314	165·2 (±1·5)
321	72·1 (±1·5)	314	166·4 (±1·5)
321	73·5 (±1·0)	314	166·5 (±1·5)
321	73·3 (±1·5)	314	166·9 (±1·5)
321	72·8 (±1·5)	314	166·7 (±1·5)
321	72·5 (±1·5)	314	167·0 (±1·5)
321	73·2 (±1·5)	314	167·3 (±1·5)
r.m.s.	73·0 ± 0·5 (±1·5)		166·6 ± 0·4 (±1·5)

* The figures in brackets refer to the range in film thickness for a single film (compare Table 1).

† The notation used here is that recommended by van der Hoeven.⁽⁵⁾ Thus for film No. 1 the root mean square error in the mean film thickness for four determinations is ±0·1 µ. The figures in brackets have the same significance as before.

It was found that the root mean square error in the measurement of the mean film thickness was usually of the order of ±0·4 µ or less. The above method was thus capable of giving reproducible results for films supported on glass plates ranging in film thickness from 10 µ to 200 µ or greater.

THEORY OF THE APPARATUS

The following treatment for the flow of gases through hypodermic needles is an extension of the theoretical analysis given in an earlier paper$^{(4)}$ for a swelling measurement apparatus. There it was shown [p. 418, equation (6)] that Schiller's formula

$$Q = \frac{\pi \rho g H_{eff} h^3}{6\eta \log_e (R/r)} \qquad (1)$$

may be applied in the parallel plate region. The term $\rho g H_{eff}$ refers to the pressure in dyn/cm^2 at the point where the gas enters between the parallel plates. It was possible to derive, using the experimentally measurable quantities Q_0, H and H_{eff}, the expression

$$h^3 = \frac{Q_0(H - H_{eff})}{K_s H H_{eff}} \qquad (2)$$

where $K_s = \pi \rho g / [6\eta \log_e (R/r)]$. In the particular case of the swelling measurement apparatus the terms H' and H_{eff} are practically the same since there is no appreciable drop in pressure from the manometer to the entrance of the parallel plate region. However, when narrow bore hypodermic needles are used H' will be in general greater than H_{eff}. It may be shown, in such instances, that the formula

$$h^3 = \frac{Q_0(H - H')}{K_s H(H' - H'_0)} = \frac{Q_0(H - H')}{K_s H(H' - aQ_0)} \qquad (3)$$

applies. The term $H'_0 = aQ_0$ represents the drop in pressure across a given needle when the flow parameter is Q_0. Since it is assumed that Poiseuille's law holds true, then the constant a incorporates the geometry of the needle and also the viscosity of the gas. When H'_0 is very small, e.g. using short wide bore hypodermic needles, and when Q_0 is also low, it is noted that equation (3) reduces to equation (2). In any case, the result of plotting the quantities H' (or H_{eff}) and h is to produce the already familiar reverse s-shaped curves (see Figs. 4 and 5). It is now possible to differentiate equation (3), and the sensitivity is given by:

$$\frac{dH'}{dh} = -3\left[\frac{K_s H}{Q_0(H - H'_0)^3}\right]^{\frac{1}{3}} [(H' - H'_0)^2(H - H')]^{\frac{2}{3}} \qquad (4)$$

This reduces to

$$\frac{dH_{eff}}{dh} = -3\left[\frac{K_s}{Q_0}\right]^{\frac{1}{3}} \cdot [H_{eff}^2(1 - H_{eff}/H)]^{\frac{2}{3}} \qquad (5)$$

when $H'_0 \rightarrow 0$. The condition for maximum sensitivity, i.e. when $d^2H'/dh^2 = 0$, may be obtained from equation (4) by further differentiation; and is found to correspond to the condition $H' = \frac{2}{3}H + \frac{1}{3}H'_0$. This expression reduces to $H_{eff} = \frac{2}{3}H$ when $H'_0 \rightarrow 0$.

TESTING THE THEORY

A series of nitrogen flow experiments at 19° C were carried out using various hypodermic needles. In one set of experiments, illustrated in Fig. 4, the same hypodermic needle was used while Q_0 was varied from 0·34 to 0·98 cm^3/s. In Fig. 5 the flow behaviour of nitrogen with different needles for a fixed value of $Q_0 = 0{\cdot}56$ cm^3/s is shown. For comparison purposes the latter figure includes the results, with the same value of Q_0, for the previously mentioned swelling measurement apparatus. In the figures the experimental points are shown as circles, while the smooth curves are constructed by assigning different values of H' in equation (3) in order to obtain the theoretical values of h. In all experiments the value of H was kept constant to 37·7 cm of water.

Referring to the curves in Figs. 4 and 5 it is observed that the agreement between the theoretical and experime values of h is best when Q_0 is low, and also when the p separation h is small. Thus in the family of curves in Fi [hypodermic needle B.w.g. 22 (A)] it is seen that the ef of reducing Q_0 is to bring the experimental points closer the theoretical curves over a wider range of H' values. Fig. 5 it is observed that the experimental results are in v good agreement with the theory for the swelling measureme apparatus [curve (i)], and in much poorer agreement for t hypodermic needle B.w.g. 22 (B) [curve (iv)].

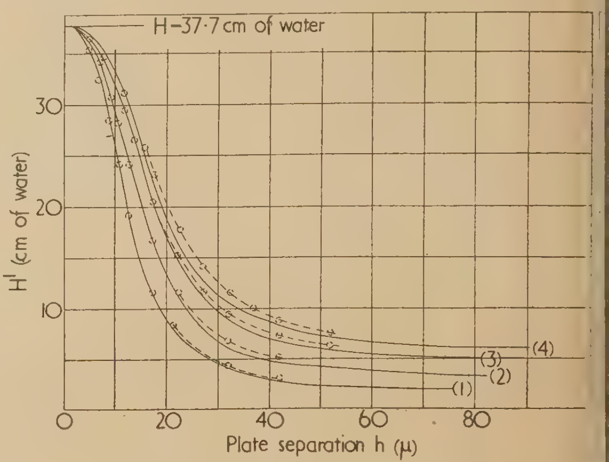


Fig. 4. Nitrogen flow through a hypodermic needle [B.w.g. 22 (A)] at 19° C

(1) $Q_0 = 0{\cdot}34$ cm^3/s; $H'_0 = 2{\cdot}0$ cm water.
(2) $Q_0 = 0{\cdot}56$ cm^3/s; $H'_0 = 3{\cdot}2$ cm water.
(3) $Q_0 = 0{\cdot}83$ cm^3/s; $H'_0 = 4{\cdot}8$ cm water.
(4) $Q_0 = 0{\cdot}98$ cm^3/s; $H'_0 = 5{\cdot}95$ cm water.

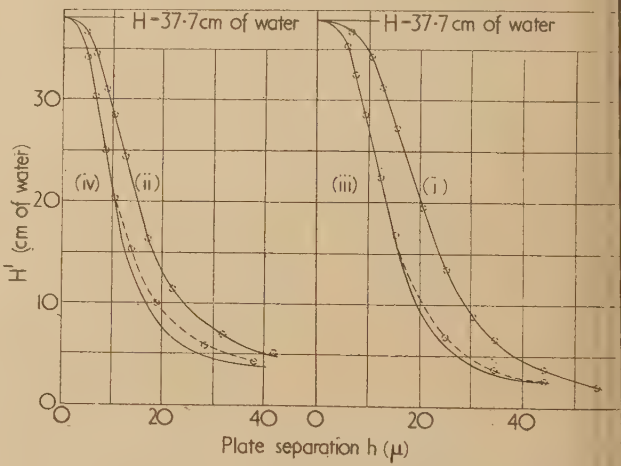


Fig. 5. Nitrogen flow through various hypodermic needles and through a swelling measurement apparatus at 19° C for a fixed value of $Q_0 = 0{\cdot}56$ cm^3/s

(i) swelling measurement apparatus.
(ii) hypodermic needle B.w.g. 22 (A).
(iii) hypodermic needle B.w.g. 20.
(iv) hypodermic needle B.w.g. 22 (B).

The maximum sensitivities for the various instrumen whose flow behaviour is described in Figs. 4 and 5, a recorded in Table 3. Some additional results are included i this table in order to present a more complete picture. Th

rimentally observed maximum sensitivities are obtained
ı the steep portions of the respective H' *versus* h curves,
e the theoretical maximum sensitivities are obtained
er from equations (4) or (5). The values of K_s and the
ensions of the instruments are also given.

able 3. *Maximum sensitivities for various instruments*

Instrument	Q_0 (cm^3/s	(dH'/dh) *expt.* (cm/μ)	(dH'/dh) *theor.* (cm/μ)	$10^6 \times K_s$ (s^{-1} cm^{-1})
swelling	1·210	1·14 ± 0·05	1·15	1·25
measurement	0·805	1·30 ± 0·05	1·31	
apparatus	0·413	1·56 ± 0·10	1·63	
needle B.w.g.	0·98	1·35 ± 0·05	1·50	4·71
22 (*A*)	0·83	1·45 ± 0·05	1·63	
	0·56	2·00 ± 0·05	1·97	
	0·34	2·50 ± 0·10	2·41	
needle B.w.g.	0·81	1·80 ± 0·05	1·98	6·00
20	0·56	2·10 ± 0·05	2·30	
needle B.w.g.	0·98	1·73 ± 0·05	2·21	12·30
22 (*B*)	0·56	2·40 ± 0·05	2·72	
	0·31	3·15 ± 0·10	3·44	

nensions:

(i) inner diameter, 0·105 ± 0·001 cm; outer diameter, 1·10 ± 0·002 cm; length, 3·60 cm.

ii) inner diameter, 0·039 ± 0·0004 cm; outer diameter, 0·073 ± 0·0003 cm; length, 1·96 cm.

iii) inner diameter, 0·056 ± 0·0004 cm; outer diameter, 0·092 ± 0·0003 cm; length, 1·98 cm.

iv) inner diameter, 0·041 ± 0·0004 cm; outer diameter, 0·052 ± 0·0015 cm; length, 1·98 cm.

he calculated and experimental sensitivities are observed
be in reasonably close agreement throughout, especially in
truments (i) and (ii). If the different needles (ii), (iii) and
are compared for $Q_0 = 0\cdot56$, the sensitivity is altered
m 2·00 to 2·40 cm/μ, which is also in the direction of
reasing K_s. For a given value of Q_0 the sensitivity is
portional to $K_s^{1/3}$. From the point of view of designing a
dle with high sensitivity, as large as possible a value of
should be sought. At the same time the gas flow para-
ter Q_0 should be at a low value. However, with too large
ues of K_s and with too low values of Q_0 the apparatus is
served to respond very slowly. Thus in practice it is not
irable to push the sensitivity too far.

he smallest change in H' measurable on the manometer of
gas flow system (Fig. 2) is ±0·01 cm. For the various
odermic needles operating under typical experimental
ditions, e.g. nitrogen flow with $Q_0 = 0\cdot56$ cm^3/s,
$= 37\cdot7$ cm water and $H' = \frac{2}{3}H$, the smallest measurable
nge in h should range from ±0·04 to ±0·05 μ. Even
h a good grade microscope focusing mechanism it is not
sible to measure such small vertical displacements. At
t the smallest change in h which can be read from the
le of the focusing mechanism is ±0·2 μ, which corresponds
approximately ±0·05 cm of water pressure in H'.

INTERPRETATION OF THE DIVERGENT RESULTS

In the derivation of the foregoing equations it has been tacitly assumed that the flow of gas is laminar throughout the system, and that the flow velocities are not too great. If this is not so then the various equations based on Schiller's formula and Poiseuille's law would no longer apply rigorously. In practice, the flow velocities are always below the threshold values for turbulent flow, but occasionally may reach such high values that kinetic energy corrections must be considered in the derivation of the pertinent flow equations. Thus in applying Schiller's formula it is assumed that the velocity of efflux at radius R is low, otherwise a kinetic energy correction term$^{(6)}$ of the form mv^2/g (where v is the efflux velocity at R, and m is a numerical constant of the order of unity) must be subtracted from H_{eff} [see equation (1)].

For the given value of $Q_0 = 0\cdot56$ cm^3/s, and for a fixed plate separation of 50 μ, the efflux velocities have been calculated for each of the instruments described in Table 3. The values of v were found to be 32, 390, 490 and 685 cm/s respectively for the swelling measurement apparatus (i), needles B.w.g. 20 (iii), 22 (A) (ii) and 22 (B) (iv). These velocities are, of course, inversely proportional to R. In general, greater kinetic energy corrections are indicated when R is small and when Q_0 is large. Thus under such conditions departures from equations (2) or (3) are expected, as observed experimentally. For even large values of Q, when h is decreased to below certain values, the conditions of flow may be such that the efflux velocity is sufficiently low for agreement with the theory to be obtained. This explains why in Figs. 4 and 5 the experimental points, corresponding to low values of h, fit the curves more closely.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. S. Rees Jones, Lecturer-in-Charge, Department of Technology, Courtauld Institute of Art, and the late Professor H. Terrey, Department of Chemistry, University College, for their kind interest shown in this work. This paper is a portion of a University of London Ph.D. thesis.

REFERENCES

(1) Gardner, H. A., and Sward, G. G. *Physical and Chemical Examination of Paints, Varnishes, etc.*, p. 141 (Bethesda, Maryland: Gardner, 1950).

(2) Spilsbury, R. S. J. *National Physical Laboratory, Annual Reports*, p. 94 (London: H.M. Stationery Office, 1922).

(3) Quarendon, R. *Engineer*, pp. 130–133, 162–166 (1953).

(4) Stolow, N. *J. Sci. Instrum.*, **31**, pp. 416–420 (1954).

(5) van der Hoeven, H. W. *F.A.T.I.P.E.C. Congress on the Physical Examination of Paints*, pp. 160–166 (Fédération d'Associations de Techniciens des Industries de Peintures, Vernis, Emaux et Encres d'Imprimerie de l'Europe Continental, 1953).

(6) Barr, G. *Viscometry*, p. 145 (London: Oxford University Press, 1931).

A semi-conducting antimony bolometer

By E. J. Gillham, M.A., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 30 *April*, 1956]

Thin films of a semi-conducting form of antimony prepared by sputtering from a cathode of metallic antimony are suitable, with regard to resistivity, temperature coefficient of resistance and freedom from current noise, for the construction of bolometers of good sensitivity and of sufficiently high resistance for matching into a valve amplifier. A description is given of the construction and performance of such a bolometer, in which the antimony film is deposited on a thin plastic pellicle.

In spite of the increasing use of photoconductive cells for the detection of infra-red radiation, detectors of the thermal type, such as bolometers and thermopiles, still retain a wide field of use, and much effort has been expended on their development. One objective of this effort has been that of increasing the speed of response, in order that the "chopping" method of eliminating zero drift may be used at reasonably high chopping frequencies without undue loss of sensitivity. A type of construction adapted to this end is that in which the bolometer or thermocouple element is deposited as a thin film, by vacuum evaporation or sputtering, on to a support consisting of a pellicle of plastic material stretched like a drum across a framework.(1) Pellicles as thin as 1000 Å are easily prepared and quite robust, so that the heat capacity of the sensitive element, and consequently its response time, may be made very small.

A number of bolometers of this type have been described in which the film is of metal.(2,3) There appears to be no reference, however, to the use of semi-conducting materials. At first sight this is rather surprising, since metals have two disadvantages. Firstly, their temperature coefficients of resistance are small. Secondly, their resistivities are such that a typical metal film bolometer generally has a resistance of less than about 100 Ω, so that matching the bolometer into a valve amplifier requires a step-up transformer. It might be thought that the resistance could be increased indefinitely simply by making the film thinner. In practice, however, it is found that below a certain thickness, metal films exhibit a large temperature-independent resistivity, caused possibly by aggregation in the film, or by the effect of the film surfaces on the mean-free-path of the conduction electrons. As a result, the temperature coefficient of resistance is considerably less for the film than for the bulk metal.

The temperature coefficient of resistance of a semi-conducting material is commonly ten or twenty times that of a metal. Moreover it is to be expected that such a material will retain its high value of temperature coefficient even in very thin films, since the intrinsic resistivity will be high compared with the temperature-independent resistivity due to aggregation or surface effects. In any case, owing to the high resistivity of the material, the film thickness in a bolometer of suitable resistance would usually be well above that for which surface effects are significant. Unfortunately, there are very few suitable semi-conducting materials which can be deposited as thin films by evaporation or sputtering without adverse effects on their properties. Moreover, such films as have been prepared often generate considerable current noise. It has been found, however, that the expected advantages of a semi-conductor material may be realized with films of a semi-conducting form of antimony prepared by sputtering.

SPUTTERED ANTIMONY FILMS

The preparation of films of so-called amorphous antimo by sputtering was first reported by Kramer,(4) who show that in these films the antimony has a resistivity sev orders of magnitude greater than that of metallic antimo and a fairly large negative temperature coefficient of resistan Following this lead, antimony films were sputtered on glass from a cast antimony cathode in an atmosphere argon. The plant and method used were substantially described by Preston,(5) the essential conditions bei distance between cathode and glass, 9 mm; depth of catho dark space, 6 mm; voltage across discharge, 1 kV; curre density at cathode, 2 mA/cm^2. Under these conditions, t rate of deposition was 1·4 μg per cm^2 per s, or in terms o nominal film thickness calculated from the density of bu *metallic* antimony, about 20 Å/s.

With a sputtering time of twenty seconds, the resulti films, of nominal thickness 400 Å, appeared metallic reflexion, dark brown by transmission, and had a resistan "per square" at room temperature of about 1 MΩ, t resistivity of the film material thus being about 4 Ωc Below 150° C, the resistance varied reversibly with tem perature, with a negative temperature-coefficient of 2·0 %/° At temperatures above about 160° C, the antimony was co verted rapidly and permanently into the metallic form, t colour of the films by transmission changing from brown blue-grey, and the resistance decreasing to about 250 Ω p square. There was no evidence of any such change taki place at temperatures much lower than 160° C, even ov extended periods of time. It is interesting to note that mu thicker (1 μ) films of sputtered antimony behave in a simil way, in contrast with evaporated films, where the stabili of the amorphous form diminishes rapidly with increase thickness.(6)

USE AS BOLOMETER MATERIAL

These results indicated that a suitable strip of antimon film, sputtered on to a plastic pellicle, should constitute bolometer element of good sensitivity and with a resistanc of say 10 MΩ, suitable for matching into a valve amplifi The preparation of such an element appears, at first sigh to present some difficulty, since it is impossible to sputt on to a free, unsupported pellicle without breaking it. Ho ever, in a method commonly used for preparing pellicles, glass plate is coated with a solution of the plastic, and th solvent allowed to evaporate. This gives a pellicle in intima contact with the glass, and the bolometer element may b sputtered on to it at that stage without damaging it in an way. In the second stage of the process, the glass plate lowered slowly into water. The pellicle then separates fro the glass, floats off on the water, and can be picked up on nework. The separation from the glass does not proceed apidly as usual when the pellicle has been exposed to the ttering discharge, but the method was, nevertheless, found be practicable with a suitable plastic material, such as ystyrene or cellulose nitrate.

second difficulty arises with the blacking of the bolometer nent, necessary because the antimony film is not, itself, a d absorber of radiation. If the black which is deposited the antimony film has appreciable electrical conductivity, often happens with good infra-red absorbers, it may ously modify the electrical properties of the film. Even a y small electrical conductivity, insufficient to affect appre- bly the resistance of the bolometer element by shunting, y, nevertheless, cause excessive current noise. It was nd, however, that such effects could be reduced to manage- e proportions by using evaporated aluminium black.

CONSTRUCTION OF BOLOMETER

n view of these results, it was decided to construct an erimental bolometer, using an antimony film deposited a polystyrene pellicle. The process of construction cribed below may be followed more easily by referring to figure which shows the finished instrument. It is seen t the bolometer is of the symmetrical or compensated e, with two similar elements in series. This form was sen, partly to obviate the need for a low-noise external d resistance, and partly to facilitate the measurement of . response. It is also seen that the two portions of the licle which carry the bolometer elements are stretched oss slots cut in a rectangular piece of thin mica. The t of the pellicle extends over the whole surface of the ca, and is coated, over the shaded areas, with films of ttered gold which serve as electrodes to the elements. e mica is cemented at the back to a stiff framework of ss (not shown).

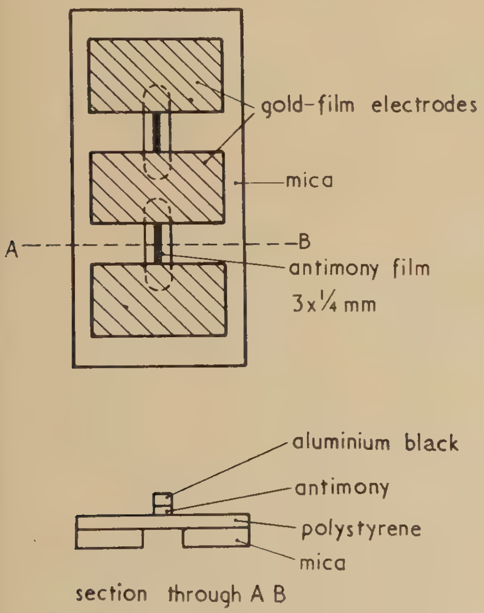


Diagram showing construction of bolometer

Details of construction were as follows. A piece of photo- phic cover glass was dipped into a solution of polystyrene toluene, drained for some minutes in the vapour above the solution, and then allowed to dry. The concentration of the solution was such as to give a pellicle thickness of about 2500 Å. Antimony was then sputtered on to the coated glass through a mask of thin metal foil with a slit-shaped aperture ¼ mm wide and about 20 mm long. This mask was held in close contact with the glass during the sputtering in order to ensure a sharp edge to the sputtered film. The sputtering time was about twenty seconds, corresponding to a film thickness of 400 Å. The electrode areas were then coated with a gold film about 400 Å thick by sputtering through a suitable mask from a gold cathode, the mask being located so that the end electrodes each overlapped roughly equal lengths of the previously deposited strip of antimony film.

The bolometer elements, consisting of the two lengths of antimony film left uncovered between the electrodes, were then coated with aluminium black by evaporating aluminium from a tungsten filament in nitrogen at a pressure of about 1½ mm of mercury, again using a suitable mask. Provided the vacuum chamber was not out-gassed too thoroughly before admitting the nitrogen, enough oxygen was usually present to ensure the production of a highly insulating coating. The coating normally used was of such a thickness as to be visually almost opaque, and weighed about 140 μg/cm^2.

The pellicle was then cut to shape by scribing lines through to the underlying glass with a razor blade and the glass plate lowered slowly into water at an angle of about 30° to the horizontal, with the result that the pellicle separated from the glass and floated off on to the surface of the water. The mica framework was then immersed in the water, and brought up just below the pellicle, in such a position that the bolometer elements were centrally disposed in the slots in the mica. The mica was then lifted out of the water, carrying the pellicle with it, a combined lifting and tilting motion being used so as to reduce the surface tension forces acting on the under side of the pellicle. After drying, the pellicle adhered reasonably well to the mica, although better adhesion could be obtained by pre-coating the mica with a thin film of Durofix.

Electrical connexion to each of the gold-film electrodes was made by means of a short length of tinned copper wire, one end of which was secured to a soldering tag cemented to the glass framework, and the other end pressed against the gold film and soldered to it with a small blob of indium.

PERFORMANCE OF EXPERIMENTAL BOLOMETER

The resistance of each bolometer element was found to be about 18 MΩ. The film resistivity, 1·5 MΩ per square, was thus somewhat higher than that of similar films on glass. This discrepancy may only indicate that the antimony film was somewhat less than 400 Å thick, owing to the shadowing effect of the mask used in the sputtering of the antimony. In other respects the films appeared quite normal, the temperature coefficient of resistance, in particular, being the same as for films on glass.

For trial, the bolometer was mounted in an airtight metal can, with a glass or rocksalt window, and was operated in air at a reduced pressure of about 1 mm of mercury. In order to secure well-defined conditions for heat loss by air conduction, the bolometer elements were backed with a glass plate situated about ½ mm behind the pellicle.

The two bolometer elements were operated in series, a d.c. voltage being applied between the top and bottom electrodes, and the signal taken from the middle one. When chopped radiation was being used, the dry battery supplying the exciting voltage was centre-tapped to earth, and the signal a.c. fed to an external amplifier. The two bolometer arms usually differed slightly in resistance, so that the signal electrode of the bolometer had a d.c. bias of a few volts. In order, therefore, to minimize the effect of leakage in the amplifier lead, the isolating condenser was selected for high insulation resistance, and was mounted inside the bolometer casing, where it could be connected to the bolometer by an air-insulated lead.

The sensitivity of the bolometer to radiation was measured with a total exciting voltage of 240 V, i.e. 120 V across each arm. Two sources of radiation were used, the first a tungsten lamp run at normal operating temperature, the second a black-painted surface at a temperature of about 180° C. The radiation, which was of course directed on to one bolometer element only, was chopped at a frequency of 10 c/s, with substantially square-wave modulation. Under these conditions, the responsivity of the bolometer on open circuit was approximately 3100 V/W for the first source, and 2300 V/W for the second, the difference between these figures indicating some fall in the absorption factor of the black toward the longer wavelengths (these responsivities are expressed in terms of the r.m.s. value of voltage and the radiant power incident on the bolometer in the open position of the shutter). The responsivity at atmospheric pressure was about two thirds that at the reduced pressure of 1 mm, in both cases.

The response was also measured using tungsten-lamp radiation modulated sinusoidally at a number of frequencies in the range 0–75 c/s. Over this range, the response was characterized by a single time constant of about 14 ms. The d.c. or steady state responsivity is more conveniently expressed in terms of d.c. rather than r.m.s. voltage. In accordance with the above figure for time constant, its value, for tungsten lamp radiation, was about 11 800 V/W.

The ultimate sensitivity of the bolometer was measured using the low-temperature source, a chopping frequency of 10 c/s, and an exciting voltage of 120 V across each element as before. The value obtained for the noise-equivalent-power (N.E.P.) in a 1 c/s bandwidth, was of the order of $1{\cdot}5 \times 10^{-9}$ W for a bolometer operated at reduced pressure, and about twice this value at atmospheric pressure. Amplifier noise appeared to be insignificant.

ANALYSIS OF PERFORMANCE

The value for d.c. responsivity to tungsten lamp radiation agreed well with the value got by measuring the resistance of the bolometer at different excitation voltages, a result which indicates that the absorption factor of the black was almost unity for this radiation. The d.c. sensitivity S should therefore be given by the equation

$$S = \frac{1}{2}\frac{\alpha}{L}E$$

where α is the temperature coefficient of resistance of the antimony film, L the heat conductance of each element to its surroundings, and E the voltage across each element (a factor of approximately unity representing the electrothermal interaction between the two elements has been omitted). Putting $\alpha = 0{\cdot}02$ per ° C, $E = 120$ V and $S = 11\,800$ V/W gives $L = 1{\cdot}0 \times 10^{-4}$ W/° C. This value indicates that the temperature of the elements, at the operating voltage of 120 V, is about 8° C above ambient.

Now it may be shown that only a small proportion of the total heat loss from the element is due to lateral conduct through the surrounding pellicle. It therefore follows t the effective area of the bolometer, so far as heat loss a heat capacity are concerned, is sensibly the same as actual area of 3 × 0·25 mm. The heat conductance per u area l is, therefore, $1{\cdot}33 \times 10^{-2}$ W per cm^2 per ° C. T heat capacity per unit area, derived from the figures previou given for thickness or mass per unit area, is given in the ta for each of the three constituents of the bolometer. Fr the total heat capacity per unit area c the time constant, got by the relation $\tau = c/l$. The agreement between value of 12·5 ms so obtained, and the measured value 14 ms, seems satisfactory in view of the uncertainty in mass per unit area figures.

Heat capacity of bolometer

Material	*Thickness (Å)*	*Mass per unit area (μg/cm²)*	*Heat capacity per unit area (J per cm² per °C)*
polystyrene	2500	26	35×10^{-6}
antimony	400	26	6×10^{-6}
aluminium	—	140	127×10^{-6}

The value given for the N.E.P. of the bolometer indica that on open circuit, and with an exciting voltage of 120 across each element, the bolometer generates about 3 μ r.m.s. noise in a 1 c/s bandwidth. About 0·4 μV of this accounted for by Johnson noise, and the remainder is p sumably due to the combined effects of current nois microphony and gas convection. The fact that the noi voltage appeared to vary little with operating pressu possibly indicates that the major part of the excess noise current noise.

DISCUSSION AND CONCLUSION

In view of the fact that the properties of a semi-conduct are often very sensitive to the amount of impurity prese it should be said that the work described here was all do using one particular sample of commercial-purity antimon The results obtained, therefore, may not be entirely typic or easily reproduced. It is hoped, however, that furth work with antimony of controlled composition will establis the precise conditions needed for the production of film similar or superior to those described.

With this reservation it may be said that the ultima sensitivity of the antimony film bolometer compares we with that of other thin film bolometers, although down by factor of ten on that of the best thermopiles of similar are and response time. Sensitivity is often the overriding con sideration in the choice of a detector, but where some latitud in this respect is permissible, the high resistance and respon sivity of the antimony bolometer may be a considerabl advantage.

It was originally hoped that time constants of 2 or 3 m would be achieved, in which case the bolometer would hav compared very favourably with other thermal detectors i those applications where rapid response is required. Thi hope was not realized, mainly because an aluminium blac prepared in such a way as to be electrically insulating, an of such a thickness as to absorb reasonably well at lon wavelengths, has, presumably unavoidably, an unduly hig thermal capacity. A good gold black, for example, migh have a thermal capacity only one-tenth the value given in th table for the aluminium black, but would almost invariabl have too high an electrical conductivity.

might be possible to overcome this difficulty, at the cost ome extra complication in manufacture, by depositing black and the antimony on opposite sides of the pellicle. insulation afforded by the pellicle might then permit the of a more efficient, electrically conducting black. A few eriments on these lines did not give very encouraging lts, however.

emi-conductor materials may therefore be inherently suitable than metals for use in thin film bolometers, when ly short response times are required. This conclusion is forced by the fact that semi-conducting films are transent at long wavelengths, so that any radiation not absorbed he overlying black is transmitted and lost. With a metal- bolometer, on the other hand, any radiation not absorbed the black is either absorbed by the film or else reflected k into the black. Thus at long wavelengths, a semiductor film bolometer requires roughly twice the thickness lack as a metal-film bolometer.

t was at first thought that the current noise generated by bolometer was the result of accidental causes such as dual electrical conduction by the black, or the strains osed on the antimony film in the process of manufacture. ther work with antimony films on glass, however, sugted that the noise was due solely to the intrinsic properties the film material, a result which is quite consistent, of course, with the behaviour of other semi-conducting materials. This being so, it might still be possible to reduce the current noise by increasing the thickness of the antimony film. The remedy is not a very practicable one, however, so that the figure given above for the N.E.P. is probably not far from the practical limit for a bolometer of this type.

ACKNOWLEDGEMENTS

The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

REFERENCES

(1) Harris, L., and Johnson, E. A. *Rev. Sci. Instrum.*, **5**, p. 153 (1934).

(2) Aiken, C. B., Carter, W. H., and Phillips, F. S. *Rev. Sci. Instrum.*, **17**, p. 377 (1946).

(3) Billings, B. H., Barr, E. E., and Hyde, W. L. *Rev. Sci. Instrum.*, **18**, p. 429 (1947).

(4) Kramer, J. *Ann. Phys.* [*Leipzig*], **19**, p. 37 (1934).

(5) Preston, J. S. *Proc. Roy. Soc. A*, **202**, p. 449 (1950).

(6) Götzberger, A. *Z. Phys.*, **142**, p. 182 (1955).

A photoelectric microscope for the measurement of linear scales

J. S. Clark, B.Sc., A.R.C.S., and A. H. Cook, M.A., Ph.D., National Physical Laboratory, Teddington, Middlesex

[*Paper first received* 9 *April, and in final form,* 16 *May,* 1956]

A description is given of a photoelectric microscope which is suitable for the accurate measurement of linear scales of high precision. A real image of a graduation line, formed by means of an ordinary microscope objective, is caused to oscillate across a fixed slit in front of a photoelectric cell. A phase-sensitive rectifier determines when the mean position of the line image coincides with the centre line of the slit. When this is so, the d.c. output of the rectifier is zero and for small displacements of the mean position of the line image, the d.c. output—which is measured on a microammeter—is proportional to the displacement.

The standard deviation of a single setting of the microscope is about $0\cdot03\ \mu$ and by associating the microscope with an interferometer, short linear scales have been measured directly in wavelengths with a standard deviation of about $0\cdot1\ \mu$. It is thought that, with a properly designed interferometer to measure the displacement of a scale with respect to a fixed photoelectric microscope, a standard deviation of $0\cdot05\ \mu$ would be achieved.

1. INTRODUCTION

hough lengths of up to about one metre are most urately measured by optical interference methods, asurements by comparison with linear scales are still y important because they are versatile and speedy and, en proper precautions are taken, are not very inferior to erferometric determinations in accuracy.

The lines of a modern standard scale are grooves, usually ween 1 and 10 μ wide, ruled with a diamond on the flat lished surface of a metal bar transversely to its longitudinal s. The length defined by two such lines is the mean aration of those parts of the lines intercepted between two er lines, usually $0\cdot1$ to $0\cdot2$ mm apart, ruled parallel to the gitudinal axis of the bar. To compare two standards of same nominal length each is brought in turn under two crometer microscopes rigidly fixed at a separation equal to nominal length of the standards, while to intercompare various intervals on a subdivided scale, the scale is moved ng under the microscopes, now fixed at a distance apart equal to one of the subdivisions, so that each subdivision in turn comes under the microscopes. The eyepiece micrometer of each microscope has a pair of parallel cross-wires with a separation equivalent to about 15 μ in the object plane (for line widths up to 10 μ) and the measurements consist in setting these cross-wires on the image of the line so that the two clear spaces between line and cross-wire appear equal for that part of the line lying between the longitudinal lines. The standard deviation of a single setting is about $0\cdot3\ \mu$ in the object plane for microscopes with magnifications about 100.

Most observers set the cross-wires asymmetrically on the line but, provided this personal error does not change, it may be eliminated by taking two sets of observations, one from each side of the scale. There is, however, some evidence that the personal error does drift and that successive settings are fairly closely correlated (the correlation drops rapidly for longer intervals between settings). The photoelectric microscope described in this paper has been developed with the objects of improving the setting accuracy, eliminating personal errors and speeding up the measurements. An image of the line under observation is formed in the plane of a fixed slit, the longer axes of the image and slit being adjusted to be parallel, and is made to move back and forth across the slit by an oscillating mirror placed in the optical path. If the mean position of the line image is symmetrical on the slit, then the light transmitted by the slit varies periodically at twice the frequency of the mirror oscillation, but if the mean position of the image is slightly displaced, then, as is explained in the Appendix, the light transmitted by the slit has a small component that varies with the same frequency as the mirror oscillation. The light passing through the slit falls on a photoelectric cell, and a phase-sensitive rectifier picks out from the current developed in the cell the component with the frequency of the mirror oscillation. The output of the rectifier is therefore zero when the mean position of the line image is symmetrical on the slit and, otherwise, is proportional to the displacement of the mean position of the image and therefore to the displacement of the object line from the optical axis of the microscope. The factor of proportionality depends on a number of conditions some of which, such as the intensity of the illumination of the object, are difficult to keep constant; the present instrument has therefore been used solely to indicate a fiducial position.

It would be possible to make a microscope in which the image did not oscillate across the slit and in which the change of position of the image was indicated by the change of light transmitted; but in such a static system this small change would have to be measured against the background of the transmitted light which, especially for images of low contrast such as those usually met with, is very many orders greater than this variation.

Furthermore, the phase-sensitive rectifier is not the only possible way of determining when the mean position of a line image coincides with the centre line of the slit. H. Moreau* has described the principle of a photoelectric microscope developed by M. Koulicovitch for la Société Genevoise d'Instruments de Physique, and used by them in a longitudinal comparator for calibrating their sub-divided linear scales. In their instrument the line is scanned by an image of the straight filament of a projector lamp focused on it, and a direct measurement of time interval rather than of phase is used to determine the displacement of the line from the optical axis of the microscope.

2. DETAILS OF MICROSCOPE

To enable the experimental microscope to be readily clamped into existing N.P.L. comparators and measuring machines, the diameter of the main body tube is the same as that of existing conventional micrometer microscopes (nominally 30 mm), and the lower end carries a standard microscope thread so that it will take any standard objective lens. The scale is illuminated by the Pointolite lamp *L* held in the housing fixed to the upper end of the microscope tube (Fig. 1). A condenser lens *C* forms an image of the source on the back surface of the objective lens *O* and the latter forms an image of the condenser lens on the surface of the scale. Part of the light reflected back from the polished surface into the objective lens is deflected by the semi-reflecting plate *R* (shown as a horizontal ellipse in Figs. 1 and 2), then by the oscillating mirror *M* to form an image in the plane of the slit *S*, and finally passes to the photocell *P*. Light scattered from the line is not reflected back into the objective lens the image of the line therefore appears dark in a bright fi

The mirror *M* is fixed to the suspension S_2 of the co of a modified moving-coil galvanometer shown in Fig. 3, assembly being suspended by phosphor bronze strips S_1

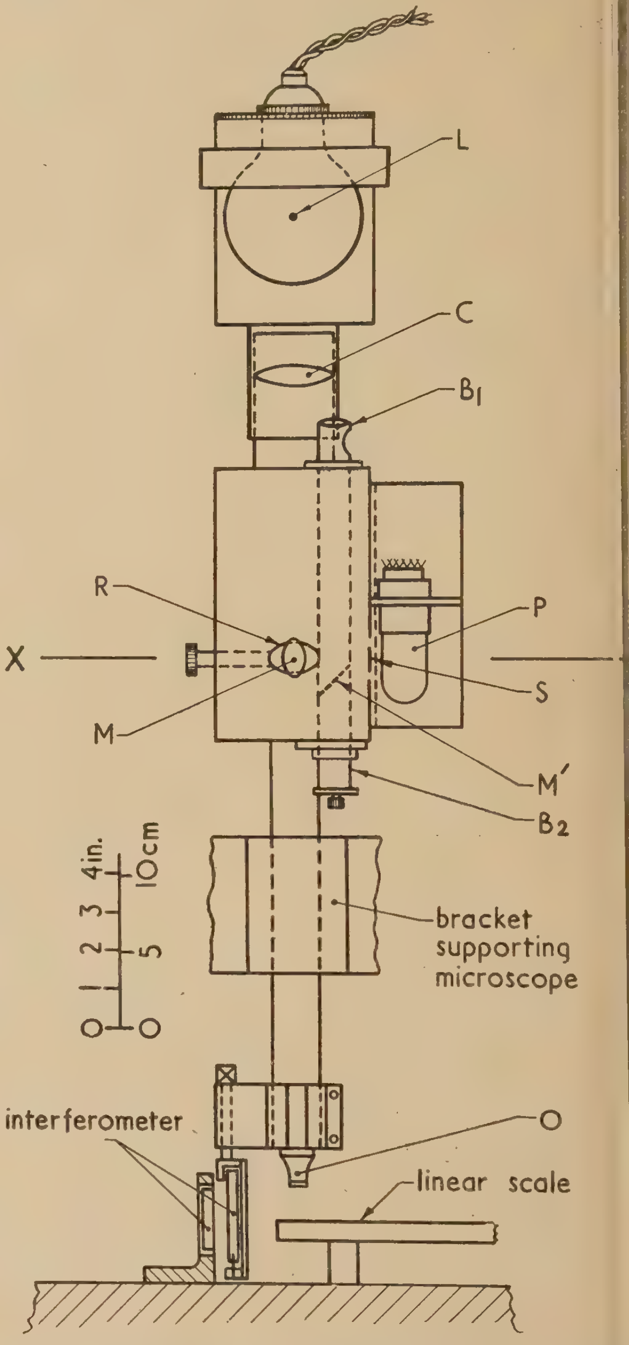


Fig. 1. Front view of photoelectric microscope with interferometer attachment (diagrammatic)

S_2 between the poles P_1 and P_2 of a permanent magne The strips are under tension and the natural frequency of t system may be varied. The line image is focused in the pla of the slit and the length of the slit can be altered with mas so that only the part of the image between the usual pair longitudinal lines (referred to above) falls on the photoce ich is as near to the slit as possible. It will be shown ections 4 and 5) that the focusing is not so critical as it is en making visual observations with a conventional micro-eter microscope. An image of the line under observation y also be formed in the focal plane of the auxiliary eyepiece (Fig. 1) by reflexion from the retractable mirror M' carried the stem B_2. The eyepiece carries a graticule to facilitate ting the scale correctly under the microscope.

---

* Moreau, H. *Mesur. Contrôle Industr.*, **16** (165), p. 51 (1951).

The photocell P is a photomultiplier with nine dynodes, d for convenience its associated potential divider is housed

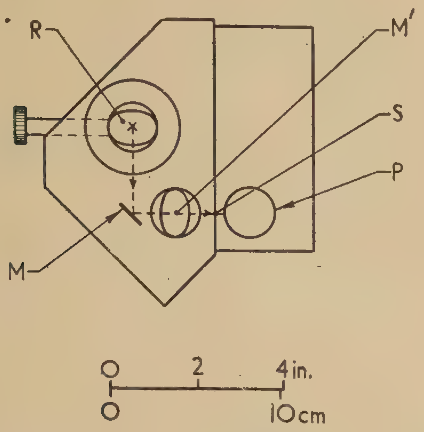


Fig. 2. Cross-section (diagrammatic) of body of microscope at level XY (Fig. 1)

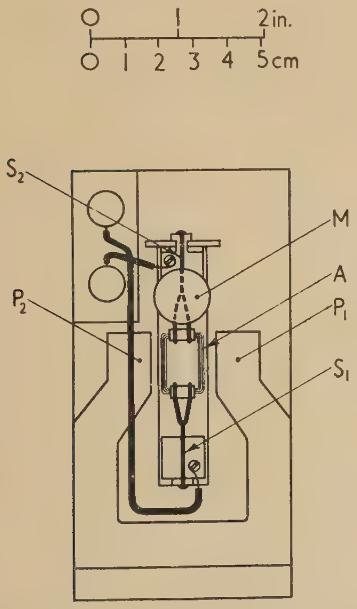


Fig. 3. Oscillating mirror assembly (elevation)

ith P in the rectangular enclosure shown to the right of g. 2. The remainder of the electrical equipment is separate om the microscope and is described in Section 3.

3. ELECTRONIC CIRCUITS

A block diagram of the electronic circuits is shown in g. 4 and the circuit of the phase-sensitive rectifier and sociated items in Fig. 5.

The phase-sensitive rectifier consists of a system of four germanium diodes, r_1–r_4, each connected as shown in series with a trimming resistor to equalize the forward resistances. A centre-tapped transformer T driven by a master oscillator is connected across one diagonal and provides the reference or polarizing voltage while the signal voltage is developed across the potentiometer chain AA', connected across the other diagonal of the rectifier. To make the potential of the mid-point P of the potentiometer chain zero, equal and opposite voltages are developed in each half of the chain by the two cathode follower valves V_3 and V_4, which are driven by equal and opposite voltages obtained from the phase-splitting combination V_1 and V_2.

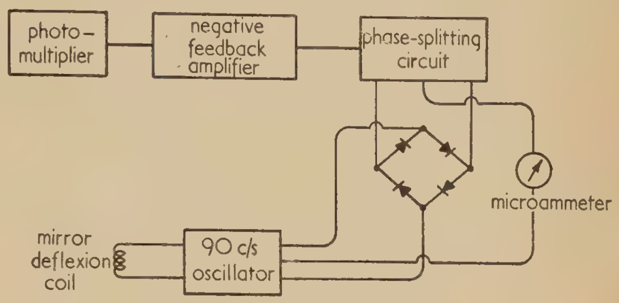


Fig. 4. Block diagram of electronic circuits

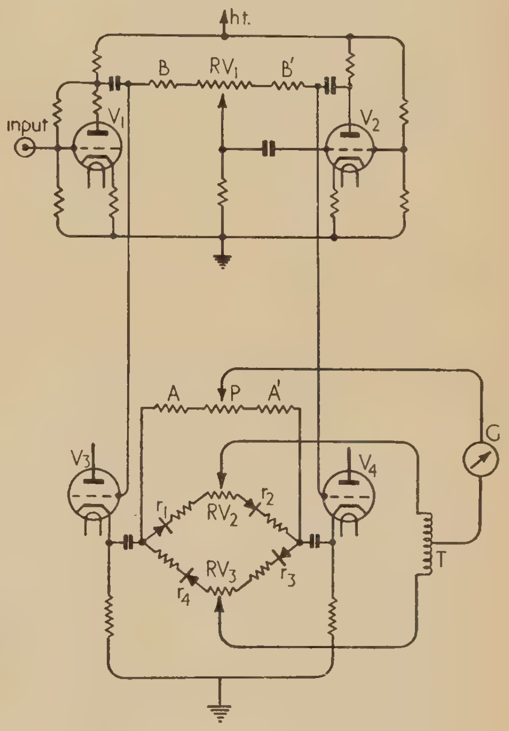


Fig. 5. Phase-splitter and phase-sensitive rectifier

Normally, therefore, the potentials of the mid-point P of the potentiometer chain and the centre tap of the transformer T are both zero, but if the signal and polarizing voltages have the same frequency a d.c. potential is developed between these points and current flows through the galvanometer G.

The amplifier following the photomultiplier has considerable negative feedback and low gain and the master oscillator which drives the oscillating mirror and provides the reference voltage is a resistance capacity oscillator. The high-tension voltages for the photomultiplier and for the other electronic circuits are obtained from well stabilized power units.

The first step in adjusting the circuits is to obtain equal and opposite voltages at the cathodes of V_3 and V_4; this is done by applying a 90 c/s sinusoidal signal to the grid of V_1 and adjusting the grid tapping point of V_2 on the potentiometer chain BB' between the anodes of V_1 and V_2. With equal and opposite voltages appearing at the cathodes of V_3 and V_4, the tapping point P may be set to the mid-point of the chain AA'. A 90 c/s sinusoidal signal is now applied to the transformer T and by altering the potentiometers RV_2 and RV_3 the rectifier is balanced. This condition is shown by no current flowing through the galvanometer G. The frequency 90 c/s is chosen to avoid possible disturbance due to the natural frequency of the oscillating mirror system being 70 c/s and the mains frequency 50 c/s.

4. PERFORMANCE

The performance of the experimental photoelectric microscope was investigated by substituting it for the conventional optical microscope in the 6 in. travelling microscope described in the N.P.L. Report for 1923.* This instrument can be read to $0 \cdot 1\ \mu$ and for fine adjustment is provided with a tangent screw whereby the microscope can be advanced by as little as $0 \cdot 02\ \mu$. This enabled the photoelectric microscope to be set to zero microammeter reading, but measurements of displacement in terms of the screw of the travelling microscope were necessarily subject to an uncertainty of about $0 \cdot 15\ \mu$. Subsequently a flat front-surface mirror was attached to the microscope and a glass optical flat to the bed of the machine on which the linear scale rested, the two flats together forming a Fizeau interferometer with which small displacements could be measured with an accuracy of $0 \cdot 09\ \mu$. This interferometer attachment is shown diagrammatically in Fig. 1. The accuracy of measurement of larger displacements is not so high because of possible distortion of the ways of the microscope carriage associated with the greater weight of the photoelectric microscope compared with that of the conventional microscope for which the measuring machine was designed. Nevertheless, with this experimental set-up the results obtained were sufficient to indicate that a measuring machine could be designed to measure linear scales with an accuracy of the order of $0 \cdot 05\ \mu$.

Experiments were made with a number of scales having good quality lines of widths ranging (on different scales) from about 1 to 7 μ (0·000 04 to 0·0003 in.). Various objective lenses were used with these different line widths so as to obtain line image widths—in the plane of the slit—ranging from about 10 to 150 μ. The slit was adjustable and provided with a micrometer whereby its width could be measured to 1 μ. The amplitude of scan (at the slit) produced by the oscillating mirror was 29 μ per 1 mA (r.m.s.) driving current up to 4 mA, and the signal-to-noise ratio was found to be about ten when the voltage supplied to the cathode of the photocell was −700 V, the Pointolite lamp being run at 1·10 A.

The results of these preliminary experiments with different line image widths showed that maximum sensitivity (for a given width of line) is achieved when the slit width is from one to three times the line image width (l) and the scan amplitude is between $\frac{1}{2}\, l$ and $2\, l$. These results are sim in a general way to those predicted by the analysis of Appendix, which assumes that the line image has unif intensity, but it is clear that the way in which the sensit varies with slit width and scan amplitude depends on distribution of intensity across the line image. Sensitiv of the order of twenty to a hundred microammeter divis per micron can be obtained, and the sensitivity for a g line and magnification can always be reduced by increa the scan amplitude or the slit width or both.

Most modern scales of high quality have lines of w 3 to 5 μ; for this reason much of the subsequent work carried out with a scale having graduation lines about (actually $3 \cdot 6\ \mu$) wide. Using a 32 mm objective, the se tivity was adjusted to a convenient value about fifty mi ammeter divisions per micron. The variations in sensiti due to the following causes were investigated: (1) varia in intensity of light source, (2) variation in voltage sup to photomultiplier cell, (3) variation in h.t. supply and effect on scan amplitude, and (4) errors in focusing.

The Pointolite lamp was run off the d.c. 230 V mains an ammeter in series with the usual ballast resistance without any means of stabilizing the light intensity automa ally. Adjustments of the ballast resistance were manually as required to keep the lamp current wi ±0·01 A of the normal operating current 1·10 A. Vol fluctuations produced current variations amounting ±0·02 A causing sensitivity variations of the order of 5%

The stabilized power pack used for the photocell furnished with a voltmeter which could be read easily wi ±5 V at 700 V, the usual negative voltage supplied to cathode of the photomultiplier cell. No sudden fluctua of this voltage ever occurred but there was sometimes a s drift; this never exceeded 5 V during a working day could always be corrected, if necessary, by a slight adjustm of the voltage control knob of the power pack. A change ±5 V at 700 V produced a change in sensitivity of ab ±5%.

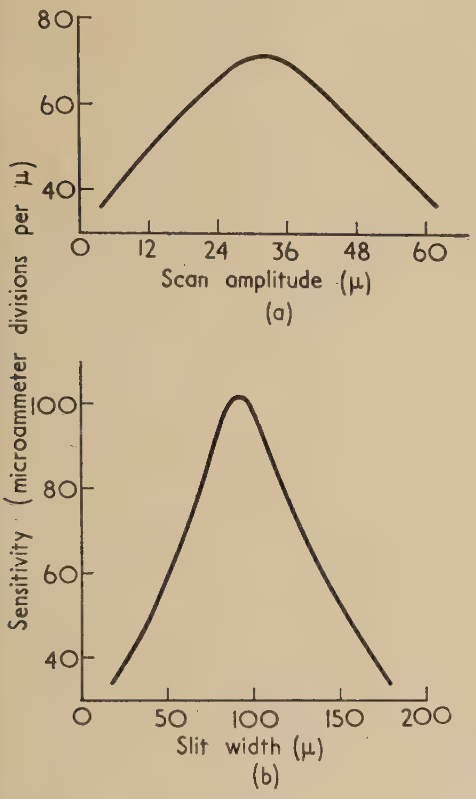
The h.t. supply to the valves of the amplifier, 90 c/s va oscillator, phase splitter and phase-sensitive rectifier circ came from another stabilized power pack. Again no sud changes of voltage occurred and such small drifts as did oc affected mostly the a.c. output of the valve oscillator. current in the mirror-oscillating circuit changed by 0·06 when the h.t. supply voltage changed by 1% at 200 V, could be easily adjusted to within ±0·02 mA of any requi value. The slow drift of h.t. voltage never exceeded 1 and in practice it was found best to correct for such drif did occur by adjusting the current in the mirror-oscillat circuit. Variations in voltage of the other output of valve oscillator do not matter because this output me provides a reference voltage of frequency equal to that of oscillating mirror. The actual voltage is immaterial so l as it exceeds that of the signal fed to the phase discriminat In practice, neither of the above possible causes of variat in sensitivity gave any trouble. Usually a single adjustm made perhaps half an hour after switching on the power all that was needed during the course of a day's work.

The effects of changes in focus on sensitivity were inve gated, and it was found that the sensitivity remains s stantially constant over a range of focus of 0·05 mm either side of the position of best (visual) focus. Furtherm in Section 5 it will be shown that quite large errors in focus have no effect on the accuracy of measurements carried with the photoelectric microscope used solely as a z indicator.

---

* *National Physical Laboratory Report*, p. 122 (London: H.M. Stationery Office, 1923.)

ʼig. 6(*a*) and (*b*) show how the sensitivity of the microscope en used on a typical line of width 3·6 μ (line image width out 40 μ) depends on the amplitude of scan and on the width. The maximum sensitivity, about a hundred



ʼig. 6. Effect on sensitivity of variations in scan amplitude and in slit width, line image width being 40 μ

(*a*) Constant slit width: 60 μ
(*b*) Constant scan amplitude: 33 μ

croammeter divisions per micron, occurs when the slit dth is about 90 μ and the scan amplitude about 33 μ. periments were made to determine the accuracy of a single ting of the microscope on a typical line, the sensitivity ing adjusted to about sixty microammeter divisions per cron. The interferometer attachment was used to measure placements of the microscope with respect to a fixed scale. e microammeter current was set to zero by bringing in the croscope from each side alternately, five settings being de with increasing currents in the microammeter and five h decreasing currents. Three sets of ten such observations re made, one with a uniform drift of 0·1 μ, due probably small temperature changes during the eight minutes cupied by the ten observations, one with a uniform drift 0·35 μ and the third without drift. The three standard viations were 0·033, 0·028 and 0·034 μ respectively. The ndard deviation of a single setting on a typical line y therefore be taken to be 0·032 μ. There may be a ght correlation between standard deviation and drift, t in a properly designed interferometer with adequate nperature control, the drift would be quite small and, in y case, the procedure of measurement would be designed eliminate the effects of temperature drift so long as it were iform.

5. MEASUREMENT OF SHORT LINEAR SCALES

The effect of errors in focusing on the accuracy of measurement of a linear scale was investigated by measuring the five intervals of 0·1, 0·2, . . . 0·5 in. of a 4 in. scale when set up at various distances from the microscope objective. The scale was first set up so that the images of the lines under observation were focused as well as possible visually in the plane of the slit, and measurements were made against a particular part of the screw of the travelling microscope. The distance of the scale from the microscope objective was then varied over a range ±0·003 in. from this position of best focus and the measurements repeated against the same part of the screw. The results indicated that the accuracy of measurement with the photoelectric microscope is substantially independent of the accuracy of focusing within this range.

Experiments were made with the photoelectric microscope and the interferometer attachment to measure the 0·01 in. intervals on the same 4 in. scale in order to determine the effect of using more than the prescribed length of the graduation lines. The prescribed length for this scale is 0·008 in., that being the distance between the parallel longitudinal lines referred to in Section 1. Five interferometer measurements were made on each line, first with the slit before the photomultiplier cell masked so that only the portion of the graduation line between the longitudinal lines was effective. The mean of each of these five results, which had a standard deviation of $3 \cdot 7 \times 10^{-6}$ in., is given under *A* in the table.

Effect of variation of effective length of line

Interval	*A* *Slit masked* *Length of line* 0·008 *in.*	*B* *No mask* *Length of line about* 0·03 *in.*
0 to 0·01 in.	0·010 095 in.	0·010 094 in.
0·02	0·020 096	0·020 094
0·03	0·030 103	0·030 102
0·04	0·040 049	0·040 048
0·05	0·050 097	0·050 094
0·06	0·060 118	0·060 117
0·07	0·070 094	0·070 085
0·08	0·080 049	0·080 047
0·09	0·090 123	0·090 121
0·10	0·100 114	0·100 118
standard deviation for $n = 50$	$3 \cdot 7 \times 10^{-6}$ in.	$3 \cdot 3 \times 10^{-6}$ in.

Five more interferometer measurements were then made with the mask removed so that the whole length of the slit (about 0·3 in.) was used, corresponding with about 0·03 in. length of graduation line. These results, with standard deviation $3 \cdot 3 \times 10^{-6}$ in., are given under *B* in the table. Except in the case of the interval 0/0·07 in. where *A*–*B* was 9×10^{-6} in., there was no significant difference between the two sets of results. The interval 0/0·07 in. provides an illustration of an additional advantage of the photoelectric microscope, because visually there was no difference in the appearance of the 0·07 in. line between the pair of longitudinal lines and beyond those lines when examined under a magnification of about fifty. When the mask is properly positioned, it is obvious that the photoelectric microscope only takes account of the prescribed part of the graduation line, but when making visual settings with a conventional micrometer microscope in which the graticule lines may extend right across the field of view, it is difficult, if not impossible, to ignore completely the parts of the image which lie beyond the longitudinal lines.

In this connexion it should be noted that when measuring a scale with a photoelectric microscope great care should be taken that dust is not allowed to settle on the scale. A particle of dust, which under a conventional microscope would readily be detected and removed, might cause anomalous results in a photoelectric microscope. For this reason any series of photoelectric measurements should be preceded and followed by a visual examination of the lines concerned, using the auxiliary eyepiece B_1 described in Section 2.

6. CONCLUSIONS

The standard (r.m.s.) deviation of a single setting with the photoelectric microscope was found (Section 4) to be 0·032 μ. The standard deviation of a single length measurement by interferometry based on the results given in the table is $3{\cdot}5 \times 10^{-6}$ in. or 0·09 μ. This is rather larger than might have been expected from the standard deviation of a single setting, but the travelling microscope and the interferometer attachment were both makeshift devices, used only to study the performance of the photoelectric microscope as a zero (fiducial) indicator. The results so far obtained indicate that if a properly designed interferometer were associated with a fixed photoelectric microscope and a movable scale, an accuracy of about 0·05 μ could be achieved in the direct measurement of linear scales. Even if the accuracy proved to be no better than 0·1 μ the labour involved in the use of the photoelectric microscope would be much less than in calibrating a sub-divided scale to this accuracy by present conventional methods.

The present method of illuminating the scale, whereby the line appears dark on a bright field, is not ideal because the mean intensity of the photomultiplier current is quite high, with correspondingly high noise, and the signal from the line image is only a relatively small reduction in this mean intensity. The photomultiplier would probably work under more favourable conditions if dark field illumination were used and it is intended to explore this possibility. With the vertical illumination used in the present experimental microscope the accuracy of a single setting on a line is of the order of 1% of the line width; the distance between two lines on a scale can only be measured with comparable accuracy if the lines (which, of course, are really grooves ruled in the polished surface of a scale) are of identical cross-section and are illuminated in precisely the same way. It is hoped that the effect of variations in line width on a given scale will be reduced or eliminated by repeating all interferometric measurements with the scale reversed end for end, the direction of illumination remaining unchanged throughout the measurements.

7. ACKNOWLEDGEMENTS

The work described above has been carried out as part of the research programme of the National Physical Laboratory, amd this paper is published by permission of the Director of the Laboratory. During the course of the work the authors have had many helpful discussions with their colleagues, particularly regarding the electronics of the instrument. The suggestion to use a phase-sensitive rectifier was due to Dr. J. A. Tanner. The instrument was made, and the electronics assembled, in the Metrology Division Workshop by Mr. N. Robinson; in the earlier stages of the experimental w valuable assistance was given by Mr. J. G. E. Hone.

APPENDIX

The sensitivity of the photoelectric microscope for a uniformly dark line image

The sensitivity of the photoelectric microscope will, general, depend on the distribution of light across the image, but the way in which the microscope works certain features of the dependence of the sensitivity on line width, slit width and scan amplitude can be underst through a study of the response of the microscope to simplest image, namely one which is uniformly dark acr its width. Since the detector measures the component of photocell output at the frequency of the image oscillati it is necessary to calculate the change in this component a small displacement of the mid position of the oscillat image, and since this paper has been concerned with microscope as a fiducial indicator, the change will be culated for small displacements from the position in wh the image oscillates centrally about the slit, for which positi by symmetry, the fundamental component of the pho electric cell output is zero. (This is so for any symmetr distribution of intensity across the image.)

Let the line image width be l, the slit width be s and sc amplitude be a, all measured at the slit plane, and define non-dimensional parameters σ and α as $\sigma = s/l$, $\alpha =$ Also let the displacement of the image at zero phase be ξ is equal to mx and l is equal to mL where m is the magnifi tion of the microscope, x the displacement of the object l and L the width of the object line. Consider first the variati of light transmitted through the slit (the "light curve") w the slit width is less than the line image width, that is less than 1. Then if the displacement of the image from central position is less than $\frac{1}{2}(l - s)$ no light will be transmitt and the amplitude of oscillation must therefore exceed t value, that is, α must be greater than $\frac{1}{2}(1 - \sigma)$ and the lig transmitted will then be zero until the phase angle of t image oscillation exceeds $\sin^{-1} [(1 - \sigma)/2\alpha]$, an angle whi will be denoted by ϕ.

If the amplitude of oscillation is less than $\frac{1}{2}(l + s)$ the li image will never wholly uncover the slit and the intensity light transmitted will be equal to $[a \sin \theta - \frac{1}{2}(l - s]I$, whe I is the amount of light transmitted by unit width of slit a θ is the phase angle of the image oscillation. When θ attai $\pi - \phi$ the transmitted light vanishes again until θ excee $\pi + \phi$. Thereafter it is $[a \mid \sin \theta \mid - \frac{1}{2} (l - s)]\ I$ until becomes $2\pi - \phi$; and finally vanishes once more until again equals ϕ. Such a light curve is drawn in Fig. 7(*a*).

Now if ξ is much less than l, s and a, as we may assu for small displacements about zero, the difference betwe the phase angle ϕ and the phase angle ϕ' at which the ima starts to uncover the slit with a displacement zero and respectively, is of order ξ/a; the only first order change the light curve is that the transmitted light will be increas by ξI between phase angles ϕ and $\pi - \phi$ and decreased ξI between angles $\pi + \phi$ and $2\pi - \phi$.

Accordingly the fundamental component of the light cur for displacement ξ is

$$\frac{1}{\pi}\int_{\phi}^{\pi-\phi} \xi I \sin \theta . d\theta + \frac{1}{\pi}\int_{\pi+\phi}^{2\pi-\phi} (-\xi I) \sin \theta . d\theta$$

$$= \frac{4\xi I}{\pi}\left[1 - \left(\frac{1-\sigma}{2\alpha}\right)^2\right.$$

now the amplitude exceeds $\frac{1}{2}(l+s)$ the slit is wholly covered by the image at phase angle ψ equal to

$$\sin^{-1}[(1+\sigma)/2\alpha]$$

d between this angle and $\pi-\psi$ the transmitted light has constant intensity sI as shown in Fig. 7(*b*). The funda-ntal component of the light curve for displacement ξ is now

$$\left(\int_{\phi}^{\psi}\sin\theta.d\theta+\int_{\pi-\psi}^{\pi-\phi}\sin\theta.d\theta\right)$$

$$-\frac{\xi I}{\pi}\left(\int_{\pi+\phi}^{\pi+\psi}\sin\theta.d\theta+\int_{2\pi-\psi}^{2\pi-\phi}\sin\theta.d\theta\right)$$

$$=\frac{4\xi I}{\pi}\left\{\left[1-\left(\frac{1-\sigma}{2\alpha}\right)^2\right]^{\frac{1}{2}}-\left[1-\left(\frac{1+\sigma}{2\alpha}\right)^2\right]^{\frac{1}{2}}\right\}$$

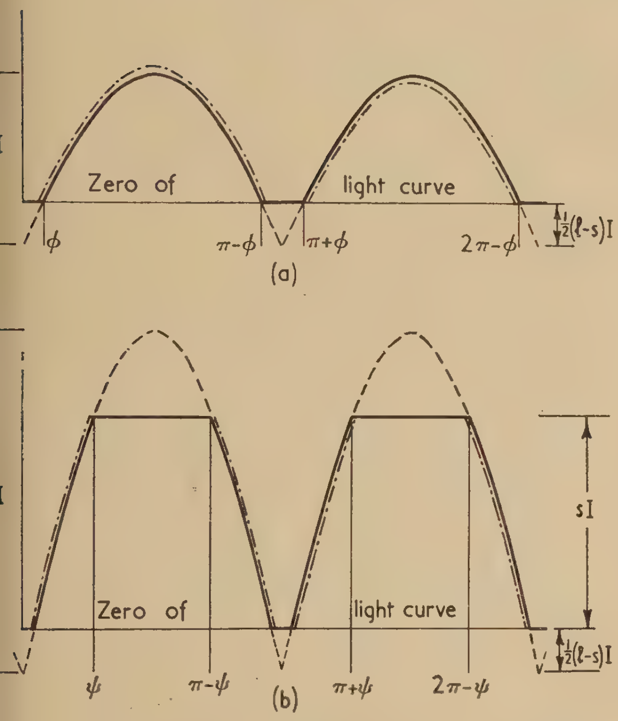


Fig. 7. Light curves for slit width s less than line image width l

(*a*) Amplitude: $a<\frac{1}{2}(l+s)$
(*b*) Amplitude: $a>\frac{1}{2}(l+s)$

Full line for $\xi=0$
Broken line for small value of ξI.

a similar way, the light curves for a slit of width greater an the line may be constructed and the fundamental components for a displacement ξ will be found to be, for amplitude less than $\frac{1}{2}(s+l)$,

$$\frac{4\xi I}{\pi}\left[1-\left(\frac{\sigma-1}{2\alpha}\right)^2\right]^{\frac{1}{2}}$$

and for amplitude greater than $\frac{1}{2}(s+l)$,

$$\frac{4\xi I}{\pi}\left\{\left[1-\left(\frac{\sigma-1}{2\alpha}\right)^2\right]^{\frac{1}{2}}-\left[1-\left(\frac{\sigma+1}{2\alpha}\right)^2\right]^{\frac{1}{2}}\right\}$$

In Fig. 8 the relative sensitivities, that is, the functions multiplying the constant factor $4\xi I/\pi$, are plotted against σ.

It cannot be expected that results obtained with the photoelectric microscope on actual lines should agree with theoretical curves calculated for such an idealized image and, in fact, the experimental observations differ from the theoretical predictions in two main ways:

> for most lines studied, the maximum sensitivity occurs at a larger value of σ, of the order of twice the theoretical value, and a high sensitivity is maintained to a larger value of σ than is predicted;
>
> the maximum sensitivity is not constant for values of α less than 1 (this feature of the theoretical curves is undoubtedly peculiar to the particular image studied).

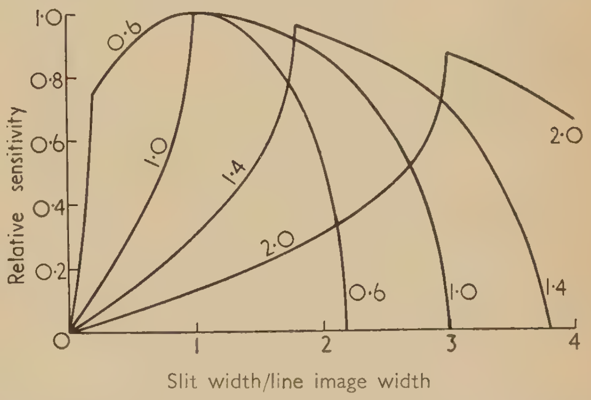


Fig. 8. Variation of relative sensitivity with the ratio σ (slit width/line image width) for various values of the ratio α (scan amplitude/line image width)

In the experimental work the line width was found by measuring directly the width of the line on the scale with a micrometer microscope and then multiplying the width so found by the magnification of the photoelectric microscope. If the distribution of intensity across the line image is not uniform it is probable that the width found in this way is less than the effective width of the image at the slit and this might account for much of the discrepancy between the experimental results and the elementary theory. Apart from this the theory satisfactorily elucidates the qualitative behaviour of the microscope and indicates which parameters are important in its design.

On preparing plastic copies of diffraction gratings; an extension to the Merton-N.P.L. process

By G. D. Dew, National Physical Laboratory, Teddington, Middlesex

[*Paper received* 18 *April*, 1956]

A process is described whereby a number of glass-based plastic copies may be prepared from a Merton–N.P.L. gelatine replica grating. These copies, considerably more stable than the gelatine replicas, may be employed as transmission gratings or aluminized and used by reflexion. By using plate glass blanks it is possible to reduce production costs while obtaining an optical quality almost indistinguishable from that of the parent replica. For moiré fringe counting applications the process may be employed in preparing copies many times the length of the original grating, all the sections being parallel and in phase. Copies prepared in this way may be recopied a number of times by the use of a slightly modified process.

Developments in the field of spectroscopy and the application of moiré fringe counting techniques to the automatic control of machine tools(1) have emphasized the need for a plentiful supply of high quality gratings. Until recently, successful use has been made of gelatine replicas derived from helical rulings by methods described in earlier communications.(2–6) Although the optical performance of such replicas has been shown to be of a very high standard, the instability of the gelatine film constitutes a potential weakness. Reflexion gratings, consisting of an aluminized layer of baked dichromated gelatine on an optically flat glass support, will last indefinitely if treated with reasonable care, but under certain adverse conditions, e.g. in a vacuum or in a desiccated atmosphere, deterioration may occur due to the complete dehydration of the gelatine film. Replicas for use by transmission must be of unhardened gelatine owing to the unsuitability of all the available hardening agents, and are therefore more vulnerable to the rigorous conditions associated with their use in some industrial applications.

Despite these disadvantages, the gelatine replica process provides the only means of accurately transferring a helical ruling to an optically flat surface. A process has therefore been devised which uses a gelatine replica as a master to prepare copies by casting with a polymerizable plastic. These copies consist of a thin layer of the polymer on a glass support and may be aluminized or not as required.

CHOICE OF PLASTIC MATERIAL AND SUBSTRATA

A preliminary survey was made of the "cold-curing" plastics commercially available to find one which would separate easily from dichromated gelatine and one of the polyester resins (Marco Resin 28C by Scott Bader and Co. Ltd.) was found to satisfy this requirement. Other resins of the same type were later found to behave in a similar manner, but the results here quoted relate exclusively to MR. 28C.

Numerous experiments were made to find methods of ensuring the adhesion of the resin to the glass support. Of these only the following need be mentioned:

(*a*) Using a glass blank with a fine "greyed" surface.

(*b*) Coating the polished glass with a thin layer of silicon monoxide by vacuum evaporation.

(*c*) Coating the polished glass with a layer of tin oxide by cathodic sputtering followed by a layer of colophony resin applied in alcoholic solution.

In order to assess the relative merits of these three methods, a number of strips of glass measuring $3 \times \frac{1}{2} \times \frac{1}{16}$ in., were treated with the substratum under examination and cemen with polyester resin to a block of the fully cured resin wit slightly roughened surface. A small area ($\frac{1}{2} \times \frac{1}{2}$ in.) of e test strip was left overhanging the edge of the block. A curing for 20 h at 20° C a series of increasing loads w applied to the overhanging portion of the test strip unt separated from the underlying resin. A sketch of apparatus used is shown in Fig. 1. The results, which purely relative, are quoted in Table 1. Under compa

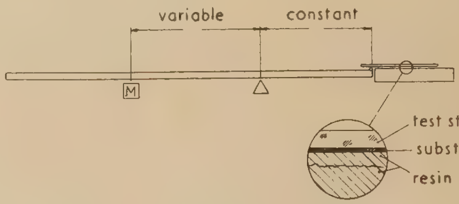


Fig. 1. Adhesion test for substrata

Table 1. *Relative efficacy of substrata*

Surface treatment	*Minimum dea load at separatio* (kg)
Fine greyed glass (Aloxite 500 mesh)	>9
Polished glass + silicon monoxide	6·7
Polished glass + tin oxide + colophony resin	4·5
Polished glass untreated	2·6

conditions the load required to separate a plastic copy fr a dichromated gelatine master lies between 2·0 and 4·5 depending on the previous history of the gelatine mast Although the concentration of dichromate in the gelatine dictated by the requirements of the gelatine replica proce it is of interest to note that a reduction in the concentrati will increase the difficulty of separation of the plastic co Some form of surface treatment is necessary to ensure t the resin, at separation, will adhere to its glass support. F reflexion gratings, the use of greyed glass is the simplest a most effective treatment. Transmission gratings intended moiré fringe counting applications may also be prepared this way, since the refractive indices of the resin and standa plate glass are similar (1·565 and 1·52 respectively for *e* line) and the optical scattering produced at the interface insignificant. For spectroscopic gratings even a small amo of scattering is undesirable and one of the vacuum-form substrata should be used, or alternatively a glass of the sa refractive index as the resin may be used.

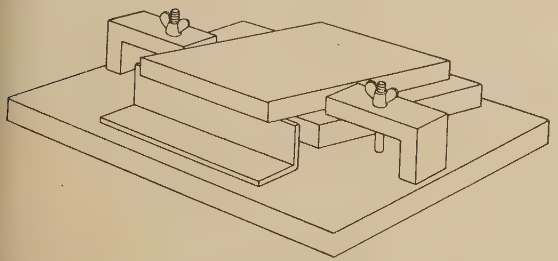
METHODS OF CASTING AND SEPARATION

lthough the constitution of the resin mixture may be ed, it is generally convenient to incorporate the maximum ommended quantity of accelerator, namely,

Marco Resin	28C	25 parts by weight
Catalyst	H	1 part
Accelerator	E	1 part

thoroughly mixed resin is filtered through fine linen to ove air bubbles and chance impurities, and a few millilitres poured on to the surface of the gelatine master. A ably treated glass blank of selected plate quality is then ered gently on to the pool of resin so as to exclude air bbles and is temporarily secured with a strip of cellulose e. After an initial period of an hour or less, depending the constitution of the resin and the curing temperature, resin has set to a gel. This is a convenient stage at which remove with a knife the surplus which has exuded from edges of the blank and to clean up any residue with tone. The cast is then set aside until the following day.

he separation of the fully cured copy from its parent atine replica presented some difficulty. The problem was in overcoming chemical adhesion but in separating two d bodies in intimate contact having exactly matching faces. Clearly the flexibility of the glass affects the ease of aration. Copies cast on ⅛ in. glass can be readily separated inserting the blade of a knife under one corner, but this thod fails with the thicker, less flexible, blanks normally d for spectroscopic gratings. Attempts to separate copies inducing a temperature gradient between the inner and er surfaces of the glass blank met with only partial success l were finally discarded in favour of the following method. lank is used of less width than the optical flat bearing the atine master, and, in casting the copy, the end of the blank jects beyond one end of the flat. Separation is then cted by supporting the overhanging edge of the blank on netal fence and applying screw pressure to the adjacent osed portions of the gelatine master (Fig. 2). This ration tends to produce a curvature of the optical flat rying the gelatine master, but the baseboard, on which reverse end of the flat rests, can oppose this tendency and y result in fracture of the flat or the blank. This difficulty be overcome by interposing a pad of felt or soft rubber ween the flat and the baseboard.



ig. 2. Method of separating plastic copy from gelatine master

CRITICAL STUDY OF THE PRODUCTS OF THE PROCESS

n appraising the quality of plastic copies prepared by the cess, a number of tests may be applied. The fullest appreciation can be obtained by employing a method first suggested by J. Guild, which uses a Fizeau interferometer to examine in turn the zero order and one or more of the diffracted order wavefronts. The test immediately relates the optical flatness of the copy and its parent grating; and, suitably interpreted, indicates how faithfully the degree of straightness, parallelism and uniformity of spacing of the grooves is maintained. Photographs of the zero and first order wavefronts of a gelatine master derived from an original plane grating of 14 400 lines/in. ruled on the Blythswood engine are shown in Figs. 3(*a*) and (*b*). The blank used in preparing the plastic copy was of selected ½ in. plate glass and its wavefront is shown in Fig. 3(*c*). Figs. 3(*d*) and (*e*) show the zero and first order wavefronts of the plastic copy. Although there is not exact correspondence between the flatness of the gelatine master and the derived copy, the optical quality of the latter is extraordinarily high. The departures from flatness are estimated as follows:

Gelatine master (zero order)	0·15 fringes	$\lambda = 0{\cdot}5461\ \mu$
Plate glass blank	5·2 fringes	
Plastic copy (zero order)	0·45 fringes	

The small difference in curvature between the master and copy gratings is attributable to the inevitable shrinkage of the resin which occurs between initial setting and complete polymerization. The contraction is estimated at approximately 5%, and it is because this value is so low that the influence of the figure of the blank is insignificant. The use of plate glass blanks obtainable for a few shillings effects a considerable saving. The gelatine masters must, of course, be prepared on optical flats costing several pounds each but these may be recovered and used again when they have given their full yield of copies. In the unlikely event of a higher standard of flatness being required in the copy, the quality of the blank must be improved accordingly. Far more serious errors of flatness may appear in the copy if an attempt is made to hasten the curing of the resin by raising the temperature. It is important that the system should be in thermal equilibrium at the time of setting, as a temperature gradient of only a few degrees can produce several fringes curvature.

Information is also required regarding the fidelity with which the form and angle of the groove faces are reproduced. Examination by means of a micro-interferometer will give some information but the method lacks the necessary precision and a comparison of the photometric properties is to be preferred. Measurements of photometric efficiency may be used not only to determine the mean angle of the groove, but will also indicate whether the shape of the groove face is preserved. The fidelity with which the grooves of the gelatine master are reproduced on the copy depends entirely on the shrinkage of the resin between initial setting and complete curing. If no such shrinkage occurred, the copy would be an exact negative facsimile of the master grating, but, as the contraction is approximately 5%, a reduction of groove angle of this order is to be expected. Premature separation of the copy should be avoided or the groove form may be severely modified during the ensuing hours when the curing is undergoing completion without the restricting influence of the gelatine master. The resulting copy then exhibits inferior photometric properties and considerable optical scatter. This occurs, to a greater or lesser extent, if less than 6 to 8 h elapse between casting and separation, but with longer periods the effects are negligible. Curing for 16 to 24 h at 20° C has been adopted as a convenient standard practice. The mean groove angles for a gelatine master

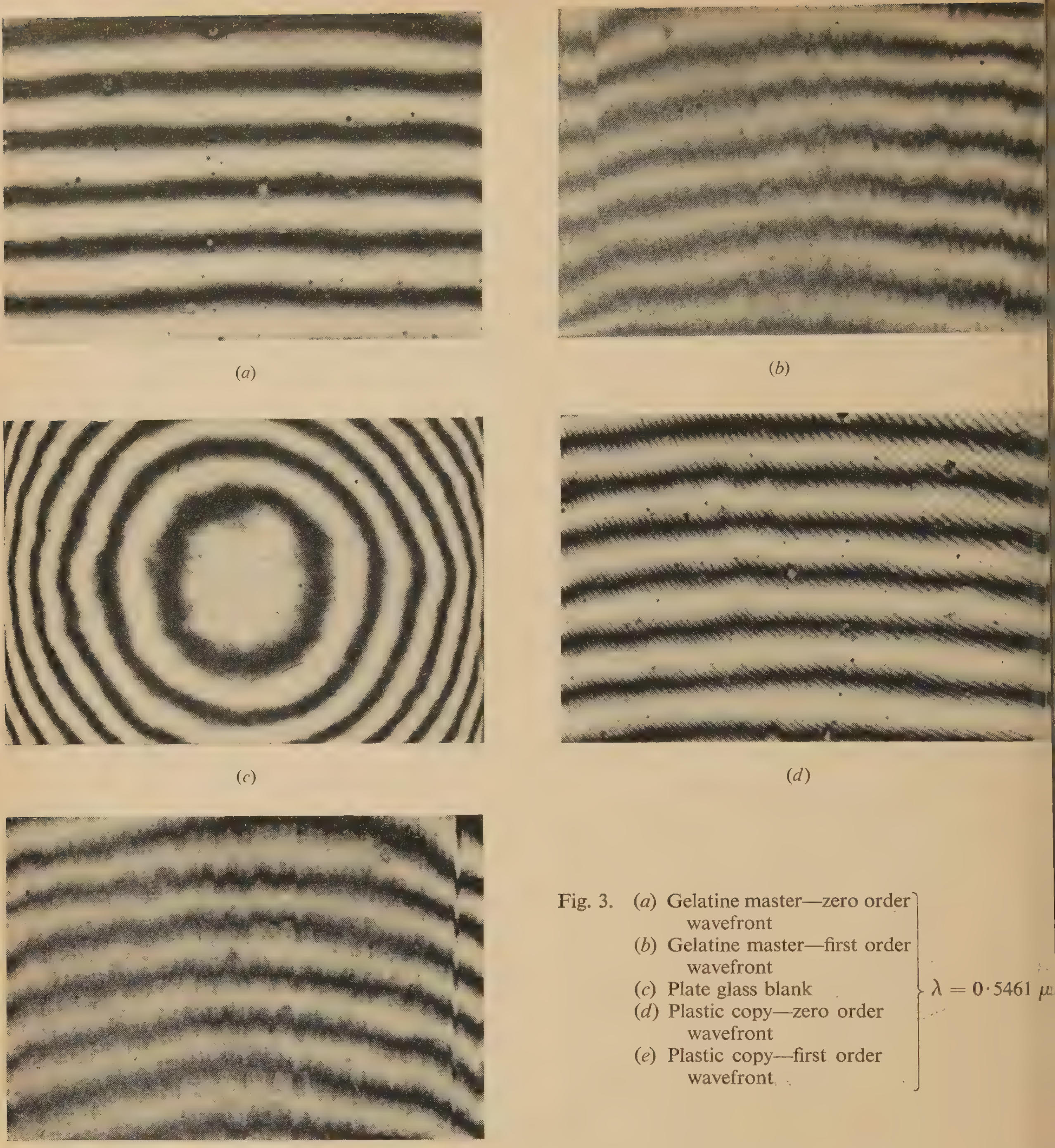


Fig. 3. (*a*) Gelatine master—zero order wavefront
(*b*) Gelatine master—first order wavefront
(*c*) Plate glass blank
(*d*) Plastic copy—zero order wavefront
(*e*) Plastic copy—first order wavefront
$\lambda = 0{\cdot}5461\ \mu$

grating and a plastic copy prepared under these conditions are given in Table 2.

A series of thirty copies derived successively from a single gelatine master were examined to determine the effective yield of the process. The photometric measurements in the two significant orders are shown in Fig. 4. In proceeding through the series, there is a slight decrease in efficiency in the sixth order accompanied by a corresponding increase in the seventh order. This implies a shift in the peak of the photometric curve towards the higher order, i.e. an increase in the mean

Table 2. *Mean groove angles for a gelatine master and its derived primary and secondary copies*

Grating	*Mean groove angle*
Gelatine master	9° 56′
Primary copy	9° 40′
Primary copy after baking at 100° C	8° 37′
First secondary copy	8° 22′
Tenth secondary copy	7° 56′

gle of the groove. Values for selected members of the ies are estimated as follows:

1st copy	9° 18′
15th copy	9° 22′
30th copy	9° 32′

nsideration of the magnitude of the measured efficiencies ables one to infer that the groove shape is well preserved oughout the series.

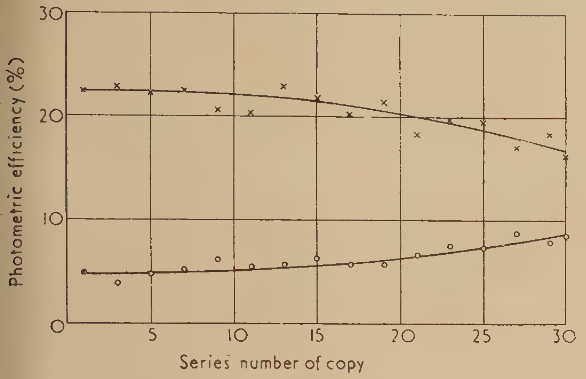


Fig. 4. Photometric properties of a series of copies obtained from a single gelatine master

× 6th order Littrow } $\lambda = 0\cdot5461\ \mu$
○ 7th order Littrow

During the preparation of this series of copies it was served that the force required for separation increased ogressively, and an independent set of measurements of eparating load" confirmed this. This phenomenon and the ange in groove angle can be explained on the assumption at the gelatine layer slowly absorbs some component of the sin. The absorbed material will not only tend to increase e affinity of the gelatine for the resin, but it will modify e groove angle of the gelatine master as each successive py is prepared.

An examination of the thirty copies from the point of view general cleanliness revealed a number of minute blemishes the later copies which were not present on the earlier embers of the series. The source of the defects can be aced to the gelatine replica process. The thinnest gelatine m normally employed, although cast at 35 μ, finally dries wn to a twelfth of this thickness, so that particles of foreign atter larger than 3 μ will protrude above the surface of the ied-out gelatine. When the copy grating is cast, the resin ts round the particle and it is subsequently detached together th a small surrounding area of gelatine. The process is mulative since a blemish is left on the gelatine master which imprinted on all subsequent copies. Attempts are being ade to improve the cleanliness of the gelatine solution by e use of finer filtering media. It should be emphasized that e blemishes do not interfere with the use of even the irtieth copy as an infra-red grating, but merely mar its pearance. In the writer's experience, the first twelve to teen copies of a series are found to be substantially free om defect, although slight variations in the standard of eanliness materially affect this yield.

Complete curing of polyester resins at room temperatures generally understood to extend over quite a long period. ertain physical and electrical properties, for instance, are und to change slowly throughout the first few weeks of the e of the resin. To determine how these changes affect the stability of gratings of polyester resin, a copy grating, stored at room temperature, was examined at intervals over a total period of 20 weeks. No detectable change in photometric properties occurred.

METROLOGICAL GRATINGS AND JOINING TECHNIQUES

The preparation of copy gratings for metrological use by moiré fringe counting methods is not fundamentally different from the method used for spectroscopic gratings. In addition to its other advantages, the technique provides a very sensitive and convenient control of grating spacing. It has been mentioned in an earlier communication(6) that the spacing of a gelatine replica differs appreciably from that of the ruling from which it was derived. The difference is due to the differential contraction between the polystyrene pellicle and the ruled cylinder when cooling after annealing. The spacing of the gelatine replica therefore depends on the materials of the pellicle and of the cylinder; also, since the absolute length of the pellicle is governed by its temperature, the drying temperature of the gelatine replica will affect the final spacing. A replica which has been dried at 20° C using a pellicle of Distrene 200 prepared from a brass helical ruling of 1000 lines/in. will have a spacing of $1003\cdot5_1$ lines/in. A plastic copy having precisely 1000 lines/in. along its axis can be prepared from such a gelatine master by inclining the blank at an angle θ to the axis of the master such that:

$$\cos\theta = 1000/1003\cdot5_1$$

The gelatine master is fixed firmly to a baseboard carrying two screw adjusters, or micrometers (Fig. 5), which serve to locate the blank at the appropriate angle.

The longest gratings which it has hitherto been found convenient to rule and to replicate by the gelatine process have been some 10 to 12 in. long. A demand for gratings several times this length prompted inquiry into methods of joining two or more sections of grating so that the several sections would be parallel and in phase with each other.

One such method emerged as a natural development of the plastic copying process. The gelatine master grating is first reduced in length so that the ruling extends to both ends of the glass. It is then mounted in a jig similar to that shown in Fig. 5 and a copy cast in Marco Resin on one end of a piece of glass of the required length. Wire spacers are employed to control the thickness of the resin film. When curing is complete, the copy is separated, and the blank moved longitudinally so that the end of the first copy just overlaps the end of the gelatine master. The blank is again located against the two micrometers and, providing the edge of the glass is sufficiently straight, it follows that the two sections of grating are parallel. The phasing adjustment is conveniently made by viewing the overlapping portion with a microscope (magnification approximately 150) and moving the blank longitudinally until the grooves of the gelatine

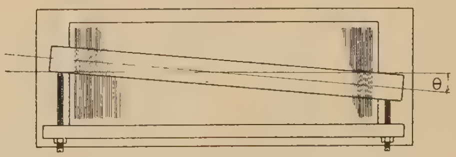


Fig. 5. Method of preparing copies of precise spacing for metrological applications

master and those of the first length of copy grating are in exact register. Seen through the microscope the crest of each groove appears as a sharply defined line and the setting can be made with great precision. Gratings of 1000 and 2500 lines/in. have been successfully phased by this method and, with a suitably modified viewing system, finer rulings are expected to present no more difficulty. When this adjustment has been made satisfactorily, resin is allowed to enter the gap between the blank and the gelatine master by capillary action. Subsequently, the copy is separated and the next section treated in a similar manner.

In practice, this basically simple method requires slight modification. The reason will be apparent if reference is made to Fig. 6 which shows in diagrammatic form a section through the region of the join. The curing of the resin forming the second section of copy is accompanied by the usual contraction in depth. This contraction is, however, rigidly opposed by the first section which controls the distance between the blank and the gelatine surface. As a result, partial separation occurs between the fresh resin and its greyed glass support. This takes the form of random snake-like threads of opacity in a region extending a few millimetres from the join. Although the performance of the grating is rarely affected, the appearance is seriously marred. The effect can be minimized by reducing the thickness of the resin film, but this increases the likelihood of air-bubbles being trapped by the resin while penetrating the narrow gap. No satisfactory compromise between the two conditions can be achieved. Attempts to prevent the inclusion of bubbles by reducing the air pressure have not been successful.

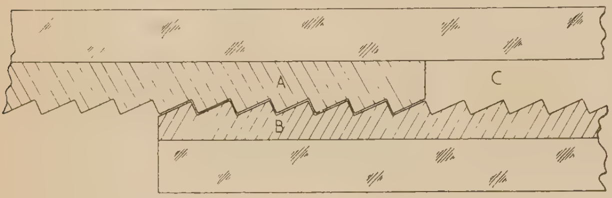


Fig. 6. Simple joining technique—diagrammatic section

A, first section of copy grating; *B*, gelatine replica; *C*, space for entry of uncured resin.

Finally, the method illustrated in Fig. 7 was evolved. The gelatine master grating is modified by cutting a slot parallel to the ruling, the width being $\frac{1}{4}$ to $\frac{1}{2}$ in. and the depth approximately half that of the glass. The isolated narrow strip of grating, which need be only $\frac{1}{4}$ in. wide, is then of necessity in phase with the main grating. The end of the first copy grating can then be made to coincide with the end of the main gelatine master without overlapping it and the contraction in depth, which is only of the order of 0·0001 in., is accommodated by the flexure in the glass underlying trough. Spacers of 0·002 or 0·003 in. can be employed, the trapping of air is completely avoided. The narrow s of grating is used for phasing and can also be employe adjusting the parallelism of the two adjacent sections grating if the straightness of the edge of the blank is inadequ For this purpose the microscope is replaced by a device viewing moiré fringes at the minimum deviation position. fringes are visible, a lack of parallelism of the two grati is indicated, and the orientation of the blank should adjusted until the fringes disappear and the field appe uniformly bright.

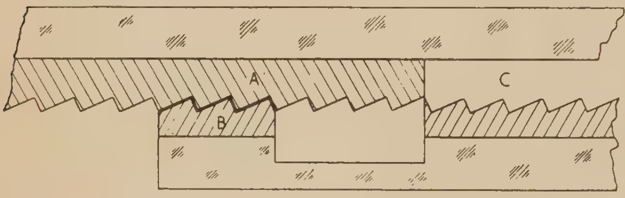


Fig. 7. Modified joining technique—diagrammatic section

A, first section of copy grating; *B*, gelatine replica; *C*, space for entry of uncured resin.

SECOND GENERATION PLASTIC COPIES

In attempting to use plastic copies as masters for preparation of further copies, several approaches w possible and many still remain to be explored. Prelimin experiments were made with various types of synthetic r in combination with a variety of mould release age Vacuum coated separating layers were avoided because the inconveniently large equipment required for long met logical gratings. Of the materials examined, the cold-sett polyester resin (MR. 28C) used for the primary copies al gave indications of success. Mixed with a trace of a silic oil (DC. 703), this material separated relatively easily fr the primary copy, although the results exhibited mu inferior photometric properties and considerable opti scatter, while succeeding copies rapidly became progressiv worse. Baking the primary copy in the range 60–140° C found to render it more stable and resistant to the uncu resin although the increased stability was obtained at expense of a reduction in groove angle. At the hig temperatures a slight modification of groove shape obtained and a temperature of 100° C was chosen as compromise. Determinations of "separating loads" for range of silicone oil contents showed that 0·25 % of the weig of the resin was a convenient minimum. It is important avoid an excess, as it is forced to the surface of the re during polymerization and collects in droplets on the surf leaving blemishes on the copies. It is of interest to note th even in the absence of the silicone, the two layers of res can be cleanly separated although the force required considerable.

A series of twenty secondary copies were prepared from primary copy baked at 100° C using resin containing 0·25 DC. 703. The photometric efficiencies (Fig. 8) again indica

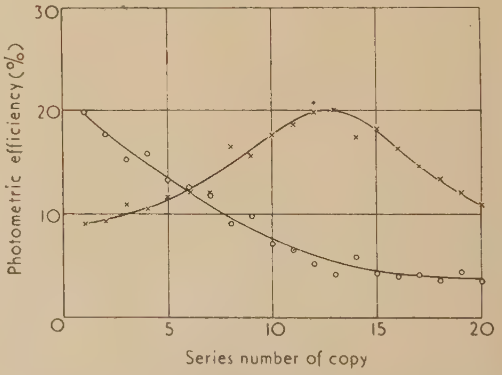


Fig. 8. Photometric properties of a series of secondary copies derived from a single primary copy

$$\left.\begin{array}{l}\times\ \text{5th order Littrow}\\ \circ\ \text{6th order Littrow}\end{array}\right\}\lambda = 0{\cdot}5461\ \mu$$

rogressive change of groove angle, the later copies being azed" in a lower order. However, no significant change groove shape is found up to the tenth copy, although severe erioration occurs thereafter.

n order that the various changes in groove angle through- t the whole process may be seen in relation to each other, an groove angles for a gelatine master grating and its ived primary and secondary copies are given in Table 2. e overall change is disappointingly large, but due allowance n be made for these losses in designing the original ruling, being known in advance whether primary or secondary ies are to be the end products. It is considered unlikely t the use of other types of resin would result in any preciable improvement, since most synthetic plastics dergo some dimensional change during polymerization.

In developing the secondary process, the intention was to ovide a means of recopying long metrological gratings ich had been prepared by the joining technique herein scribed. Its suitability for spectroscopic gratings has not been investigated, as the relatively small demands in the ectroscopic field are readily met by using the primary ocess. The nature and quantity of future demands for such gratings will clearly govern the development of these and other allied techniques.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contribution to the experimental work made by Miss S. H. Lindberg. The work described above has been carried out under the guidance of Dr. L. A. Sayce as part of the research programme of the National Physical Laboratory. This paper is published by permission of the Director of the Laboratory.

REFERENCES

(1) Williamson, D. T. N. *Machinery*, **84**, p. 1210 (1954).
(2) Merton, Sir T. *Proc. Roy. Soc. A*, **201**, p. 187 (1950).
(3) Dew, G. D., and Sayce, L. A. *Proc. Roy. Soc. A*, **207**, p. 278 (1951).
(4) Hall, R. G. N., and Sayce, L. A. *Proc. Roy. Soc. A*, **215**, p. 536 (1952).
(5) Dew, G. D. *J. Sci. Instrum.*, **29**, p. 277 (1952).
(6) Dew, G. D. *J. Sci. Instrum.*, **30**, p. 229 (1953).

A microwave thermistor calorimeter

y M. J. Smith, B.Sc., A.R.C.S., Grad.Inst.P., and J. R. M. Vaughan, B.A., E.M.I. Research Laboratories Ltd., Hayes, Middlesex

[*Paper first received* 22 *March, and in final form* 2 *May*, 1956]

The instrument described is an improved continuous-flow water calorimeter for the measurement of microwave powers from a few milliwatts upwards. Thermistors are used to measure the temperature rise of the water; their small size and high sensitivity allows the calorimeter to be relatively rugged, accurate and quick reading. The circuit is a direct reading d.c. bridge, indicating on a microammeter specially calibrated in degrees of temperature rise, and in watts of microwave power at a standard water flow rate.

A mathematical analysis is given of the four-thermistor bridge, the compensation for variations of ambient temperature, and the correction for internal heat losses. Details are given of the practical method of setting the calibration and determining the cooling correction.

Accuracy is thought to be better than ±10% for powers over 1 W at 8–9 mm wavelength, with a reading time of a few seconds.

1. INTRODUCTION

e continuous-flow water calorimeter was one of the rliest instruments used for measurement of microwave wer, having the basic advantage of an absolute calibration, d it is still in widespread use.(1,2) The principal dis- vantages have been fragility, slowness in operation and lative insensitivity. In the instrument to be described, orts are made to overcome these disadvantages, to improve e overall accuracy and to produce a calorimeter suitable th for production testing and for research on magnetron d klystron valves.

The methods used are to reduce the volume of water to e minimum while still absorbing substantially all the icrowave power, to use thermistors instead of thermo- uples for detection of the temperature rise, to reduce the th from the heating zone to the thermistors, and to avoid scontinuities which would cause sparking at high peak wers. The high sensitivity of thermistors allows the usual lvanometer to be replaced by a microammeter, with an crease in robustness of the system as a whole.

2. CONSTRUCTION

The radio-frequency head is shown in Fig. 1, the circuit of the indicating unit in Fig. 2, and the special scales on the microammeter in Fig. 3. The instrument was originally designed for *Q*-band (8–9 mm), but has been scaled to other wavelengths without difficulty. This description refers to the *Q*-band model.

Filtered distilled water enters *via* a flow control valve *A* (Fig. 1), controlling over the range 5–50 ml./min at 10 ft head. It passes over the bulb of a mercury thermometer *B* (used for calibration only) and over the beads of two thermistors *C*, *C′* (type F2311/300 by Standard Telephones and Cables Ltd.). All these components are set in a substantial brass block which minimizes fluctuations of the input water temperature. The water then passes through a silica tube *D* set at an angle of 10° between central slots in the broad faces of the waveguide. The tube bore is 0·040 in., the guide width 0·280 in., and about 0·4% of the microwave power passes the calorimeter; this error is negligible, and the reduced power is useful for operating a wavemeter or spectrometer.

A glass tube is not used as most of the power would be absorbed in the tube walls, with a consequent increase in the loss by external cooling. The slots in the waveguide are covered by grooved brass plates E, E' to prevent radiation and permit the guide to be pressurized for high power work.

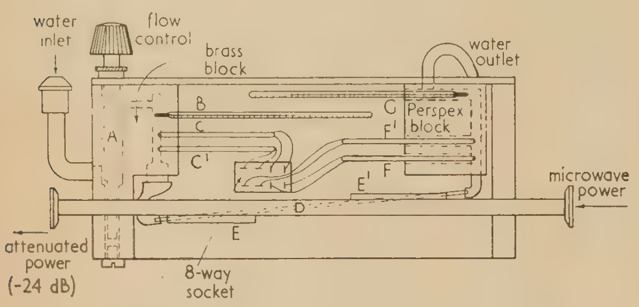


Fig. 1. Radio-frequency head for microwave thermistor calorimeter

The water then passes into a Perspex block in which are inserted two more thermistors F, F' and a second thermometer G. The distances are kept short, and the passages are constricted to keep the velocity high.

The four thermistors are connected in a bridge circuit

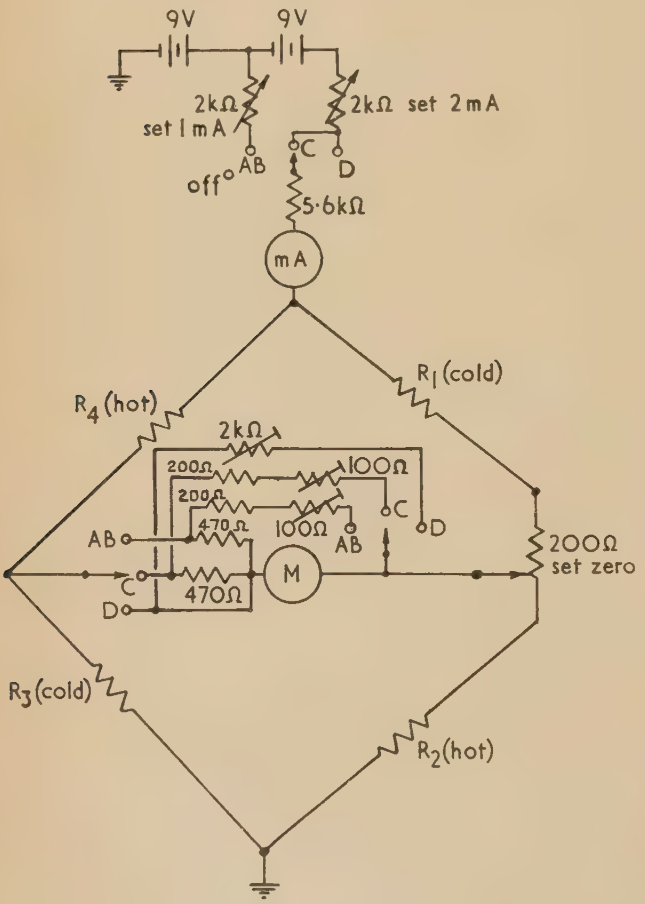


Fig. 2. Circuit connexions for microwave thermistor calorimeter

$\left.\begin{matrix}R_1 \text{ and } R_2\\ R_3 \text{ and } R_4\end{matrix}\right\}$ = matched pairs of thermistors.

M = 75 μA meter, specially calibrated.

(Fig. 2), supplied by a battery through a dropping resi the value of which is determined below. Current in galvanometer arm is measured by a microammeter switched adjustable shunts for various sensitivity rar provision is made for connecting a galvanometer v milliwatt powers are to be measured. The thermistors obtained in "matched pairs," arranged as shown, but a s potentiometer is still required to balance the bridge at microwave power input. The bridge is not re-balance operation, the unbalance current being used as a d. measure of the temperature rise of the water. Since the of thermistors raises the impedance to the 1000 Ω level, indicating unit can be at a considerable distance from radio-frequency head without requiring compensation lead resistance.

3. ANALYSIS

With the water flowing at f ml/min, a microwave powe W watts will raise the temperature by T_f (°C or °K) at the from the guide, where

$$T_f = 60W/Jf$$

(J equals Joule's equivalent).

Neglecting, for the present, any heat losses, the output thermistors are thus raised from the cold water tempera T_0° K to $(T_0 + T_f)$° K.

The resistance of a thermistor may be represented by equation

$$R = a \exp(b/T)$$

where T is the absolute temperature (°K) and

$$\left.\begin{aligned} a &\simeq 0{\cdot}35\ \Omega \\ b &\simeq 2550^\circ\ \text{K} \end{aligned}\right\}$$

for the type used. However, the manufacturing tolerance a is stated to be ±20%, so that the calorimeter requ means for setting the calibration against the standard provi by the two thermometers (Section 4).

Equations (3) represent a room temperature resistance about 2000 Ω, falling by half for every 25° C temperature r

Substituting the thermistor resistances in the usual form for unbalance current in a Wheatstone bridge,$^{(3)}$ we obt the meter arm current

$$i_m = i\frac{1 - \exp[-bT_f/T_0(T_0 + T_f)]}{1 + \exp[-bT_f/T_0(T_0 + T_f)] + 2R_m/R_c}$$

where i is the battery current, R_m the meter resistance (incl ing shunts), and R_c the cold thermistor resistance.

The sensitivity, with i constant, is

$$s = \frac{\partial i_m}{\partial T_f} = \frac{2ib(1 + R_m/R_c)\exp[bT_f/T_0(T_0 + T_f)]}{(T_0 + T_f)^2\{1 + (1 + 2R_m/R_c)\exp[bT_f/T_0(T_0 + T_f)}$$

and the initial sensitivity (at $T_f = 0$) is

$$s_0 = ib/[2T_0^2(1 + R_m/R_c)]$$

If $R_m \ll R_c$ and can be neglected, these equations reduce

$$i_m = i \tanh[bT_f/2T_0(T_0 + T_f)]$$

$$s = \frac{ib}{2(T_0 + T_f)^2}\operatorname{sech}^2[bT_f/2T_0(T_0 + T_f)]$$

$$s_0 = ib/2T_0^2$$

he maximum recommended value of i is 4 mA; assuming = 295° K, equation (6a) gives

$$s_0 = 59\ \mu\text{A}/{}^{\circ}\text{K} \qquad (7)$$

valuation of equation (5a) shows that s is substantially stant for $T_f < 15^{\circ}$ C, and falls only by 10% when = 35° C. Higher temperature rises are not used, as the lution of dissolved gases would cause difficulties. The roammeter may therefore be calibrated with temperature es linear up to 15° C, and crowding only slightly to C (Fig. 3, lower scales).

quation (7) shows that temperature changes of 0·001° C iivalent to about 0·2 mW at $f = 3$ ml./min) will be dily detected by a galvanometer. Stabilization of the inlet er temperature then becomes a difficulty: the criterion is the variation must be small compared to the rise being isured, during the time taken for water to pass from the it to the output thermistors (about ten seconds or so). s can be achieved, with some care, and the calorimeter has n used for measurement of powers of a few milliwatts, a galvanometer sensitivity of 6 mm/mW, a reading time wenty-five seconds, and a zero drift of about 2 mm/min. powers in the watt region, the reading time is three to seconds, and the zero drift is negligible.

quations (5) and (6) show that s and s_0 vary significantly T_0; if this varies by ±10° C, s and s_0 will vary by ∓6%. s error may be reduced by introducing a compensating ation of i, hitherto assumed constant: if i is supplied by attery of voltage V through a resistance R_s, and if $\ll R_c$ as before, then

$$s_0 = bV/\{2T_0^2[R_s + a\exp(b/T_0)]\} \qquad (8)$$

ıce

$$= \frac{bV}{T_0^3[R_s + a\exp(b/T_0)]}\left\{\frac{a\exp(b/T_0)[(b/2T_0) - 1] - R_s}{a\exp(b/T_0) + R_s}\right\} \qquad (9)$$

ch vanishes if

$$\begin{aligned} R_s &= a\exp(b/T_0)\,[(b/2T_0) - 1] \\ &= R_c[(b/2T_0) - 1] \end{aligned} \qquad (10)$$

stituting values

$$\left.\begin{aligned} R_s &= 6700\ \Omega \\ V &= 8700\ i \\ &\simeq 9\text{ V per mA bridge current} \end{aligned}\right\} \qquad (11)$$

tery voltages of 9 and 18 V are provided, and R_s can be isted to allow the bridge current to be set to 1 or 2 mA ectively, at the inlet temperature used for calibrating, and iout microwave power. The bridge current thus varies n either the inlet temperature changes or microwave ver is received, but it must not be reset except under the idard conditions; in practice it is stable for long periods. change of sensitivity is now +3% at ±10° C change of and +1% for ±5° C, which is usually attainable in the oratory. The temperature T_0, at which the calibration is to agree with the thermometers, may be chosen at will to local conditions.

n practice there will be some loss of heat in the pipe ween the waveguide and the thermistors; if this is il. per min per °C per cm, and the thermistors are at a ance of x cm, the temperature at the thermistors will be

$$T_0 + T_{fx} = T_0 + T_f\exp(-kx/f) \qquad (12)$$

and the apparent microwave power is

$$W_f = JfT_{fx}/60\text{ watts} \qquad (13)$$

Clearly $W_f \to W$ as $f \to \infty$, but this does not improve the accuracy, since [by equation (1)] $T_f \to 0$, so that the reading accuracy becomes low. It is therefore necessary to work at flow rates where T_f is reasonably high, and to eliminate the unknown kx in equation (12) by taking readings at two flow rates f_1 and f_2. If the corresponding apparent powers are W_1 and W_2, then the true power is

$$\left.\begin{aligned} W &= \frac{W_1^{f_1/(f_1-f_2)}}{W_2^{f_2/(f_1-f_2)}} \\ \text{or}\qquad (f_1 - f_2)\log W &= f_1\log W_1 - f_2\log W_2 \end{aligned}\right\} \qquad (14)$$

A simple case occurs if $f_1 = 2f_2$:

$$W = W_1^2/W_2 \qquad (15)$$

It is only necessary to evaluate the cooling error once, since a general correction curve can then be drawn for any rate of flow; the correction factor is

$$K(f) = W/W_f = (W_1/W_2)^{f_1f_2/f(f_1-f_2)} \qquad (16)$$

A typical correction curve for the Q-band calorimeter is shown in Fig. 4. The correction is generally discounted at flow rates above 20 ml./min, but is serious when the flow is reduced to 2–3 ml./min.

4. CALIBRATION

The calibration of the temperature scales (Fig. 3) was calculated from equation (4), using the nominal values of the thermistor constants given in equation (3). With a bridge current of 2 mA, and a temperature rise of 3·5° C (full-scale deflexion on the most sensitive range), the current in the meter arm is close to 100 μA; but to allow for the spread of values given in equation (3) among actual thermistors, a meter of higher sensitivity was used, with shunts so that each range could be adjusted to suit the thermistors employed (Fig. 2).

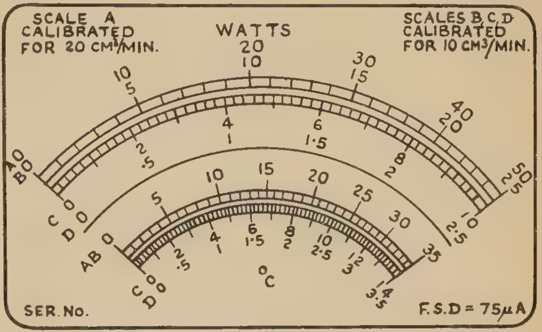


Fig. 3. Meter calibration (Q-band model)

To set these shunts, a radio-frequency power source (magnetron or klystron, etc.) is required; its power need not be known, but it must be enough to give half-scale deflexion or more on each range at some reasonable water flow rate, and it must be stable over periods of a few minutes. The power W and flow f are first set to give a temperature rise of 2 or 3° C, and allowed to run until the thermometers B and G are steady; the shunt for the 3·5° C range is then adjusted to make the meter reading agree with the difference between

B and *G*. The reading on *B* should be as near as possible to the inlet temperature expected in normal use. For the 14° C range the shunt divides the meter sensitivity by about four, and for 35° C the bridge current is halved. The shunts for these ranges are adjusted in the same way to obtain agreement with the thermometers. The instrument is then used without further reference to the thermometers, except that the calibration can be checked against them whenever *W* and *f* have been steady for a few minutes.

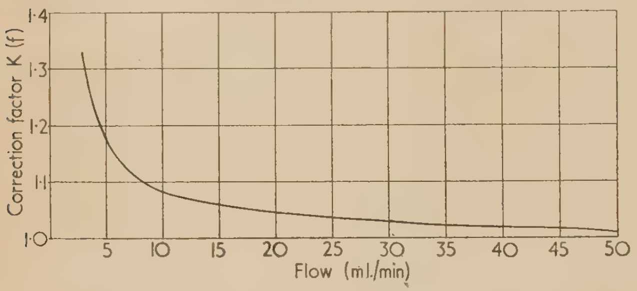


Fig. 4. Correction curve for *Q*-band model

Clearly, the bridge unit should not be used with different radio-frequency heads without resetting the shunts, or providing switched shunts in the unit.

The meter is also calibrated directly in watts, for flow rates of 10 or 20 ml./min (Fig. 3, upper scales). Originally these scales were slightly adjusted from the values calculated by equation (1), to compensate for the cooling error. When the calorimeter came to be used over a much wider range of mean powers (5 mW to 100 W) at flow rates fro 50 ml./min, it was realized that the scales should corresponded exactly to equation (1), and the correctio Fig. 4 applied when necessary.

It is believed that the overall measurement accurac better than ±5% of the microwave power absorbed addition, up to 3% may be reflected and 0·4% is transmit Comparisons between calorimeters used in different sect of the writers' laboratory generally show agreement wi 5%, and agreement with calorimeters using thermocou and galvanometers at the Services Electronics Rese Laboratory has been consistently within 10%. At powers, accuracy is naturally less, and errors in the milli range have probably been up to ±20% ± 2 mW.

ACKNOWLEDGEMENTS

The authors' thanks are due to their colleague Mr. R. Blackadder, who was responsible for much of the deta design of the first instrument. They are indebted to Managing Director of E.M.I. Research Laboratories and to the Admiralty for permission to publish.

REFERENCES

(1) Lane, J. A. *British Communications and Electronic* p. 60 (December 1955).
(2) Willshaw, W. E., Lamont, H. R. L., and Hickin, E. *Proc. Instn Elect. Engrs*, *B*, **102**, p. 99 (1955).
(3) Jeans, J. H. *Electricity and Magnetism*, 5th ed., p. (London: Cambridge University Press, 1933).

An instrument for measuring absorptivities for solar radiation

By H. Tabor, B.Sc., A.Inst.P., and I. T. Steinberger, M.Sc., National Physical Laboratory of Israel, Jerusalem, Israe

[*Paper received* 30 *May*, 1956]

An instrument and method for measuring solar absorptivities of prepared metal samples is described. By means of comparing the cooling and heating cycles, when subjected to solar radiation, of a sample plate of which one side is a standard black and the other is the test surface, most of the usual errors are eliminated and a direct comparative measure of absorptivity obtained.

It has recently been shown that the efficiency of collection of solar energy by blackened plates can be greatly improved by the principles of selective radiation.(1) Surfaces have been prepared which whilst being substantially black over the solar spectrum (approximately 0·3–2·0 μ) are, however, reflectors for wavelengths in excess of 2 μ. As bodies heated to a few hundred degrees Celsius radiate almost all their energy above 2 μ, they will be poor emitters if they are good reflectors for these wavelengths.

In the course of this work it has been necessary to measure the absorptivity to sunlight of various surfaces. Whilst some of these surfaces were specular, many were not, so that absorptivity could not be determined by measuring the reflectivity to sunlight using a solar radiation meter. It was thus necessary to build an instrument which would measure the absorptivity directly.

It was felt that certain types of classical radiometers would provide a basis for design. In such instruments the heating produced in a blackened body is a function of the absorptivity of the surface and the intensity of the measured radiation. Normally one keeps the absorptivity constant and can t determine the radiation intensity, but for the authors' purp the radiation intensity is held constant, thereby determin the absorptivity.

Radiometers are generally of two kinds, those in wh temperature equilibrium is attained and those of the d type in which changes of temperature are determined. Callender(2) radio balance is an example of the former ty and the Guild(3) radiometer and the Abbot(4) silver-c pyrheliometer are examples of the latter type.

The instruments based on temperature equilibrium usually delicate in order to provide the minimum ther capacity and rapid response. However, these instruments rather sensitive to the influence of secondary factors such ambient temperature, wind, etc. The drift type instrume are more rugged and their method of operation tends eliminate the influence of secondary factors. The ther capacity can be quite high.

As it was desired to measure absorptivity of vari samples (the thermal capacities of which might be quite hi l these measurements were to be effected in the open, it s clear that a temperature-drift method was to be pre- red. A measuring technique similar to that proposed by ild[(3)] was employed.

Guild has described a temperature-drift radiometer in ich the heat generated by radiation falling on a blackened oper disk is compared with the heat generated by an ctrical heating element embedded in the blackened face. ermocouples are used to measure the changes in the nperature of the disk with respect to that of a shielded mass. e disk is subject to cycles of heating and cooling, the ating being alternately by radiation and by electricity. mperatures are measured at fixed time intervals near the ginning and the end of each cycle as is also the electrical out, from which it is possible to compute the ratio of liation heating to electrical heating. Making the electrical wer input approximately equal to the radiation input and table choice of the temperature range result in a very high gree of accuracy, permitting the instrument to be used as orimary standard for radiation measurement. The instru- nt constructed by the authors is built on the principle of mparing the heating produced by solar radiation on a te, the surface absorptivity of which is to be determined, th the heating produced by the same radiation on the same te when its surface is of known absorptivity. In order to ect these measurements in a continuous manner, the plate s one side treated as a test surface and the reverse side ackened with lamp-black, the plate being mounted so that can be readily reversed.

GENERAL DESCRIPTION

The instrument comprises a horizontal rectangular box, × 9 × 12 cm, made of Perspex (because of its low con- ctivity), the square ends being of glass and removable. e whole box is mounted on a pyrheliometer base which rmits the box to be pointed at the sun (Fig. 1). The ounting is arranged with an indent mechanism to allow the x to be rotated 180° so that either square end of the box n be made to face the sun.

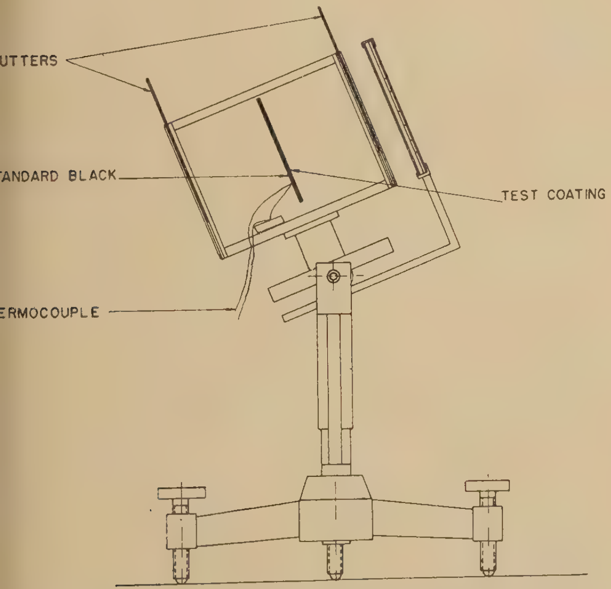


Fig. 1. Schematic diagram of the instrument for measur- ng solar absorptivities. (External shielding not shown)

At the centre of the box are two ebonite clips which permit a rectangular sample 6 × 6 cm to be held exactly parallel to the square ends of the box. This sample, usually about 2 mm thick, has one side surface treated in accordance with the type of surface to be studied, whilst the other side is blackened with lamp-black. At the centre of the disk, and on its lamp-black side, is affixed a copper-constantan thermocouple—about $\frac{1}{10}$ mm thick wire (40 s.w.g.)—which is recessed about 1 mm into the plate. The cold junction for this thermocouple is a copper plate fixed to the inside of the Perspex box.

Surrounding the box are two removable open-ended aluminium shields which prevent the ingress of radiation except through the glass windows and which also act as wind shields giving much steadier results than are obtained without them. Immediately outside the glass ends are aluminium shutters mounted in guides which allow the radiation to be cut off at will.

Outside the box and fixed to the stand is a holder into which a perforated plate can be inserted, the plate constituting a "diaphragm" which limits the amount of solar radiation which can enter the glass windows. The reason for using a perforated plate is in order that the solar radiation shall be distributed over the whole area of the test sample and not all at one region (which occurred in an earlier model when an iris diaphragm was used). Care is taken to ensure that the holes of the perforated plate do not allow radiation to fall on the sample-retaining clips nor on the spot where the measuring thermocouple is attached to the sample. The relative transmission factors for various perforated plates is determined from a measurement of the diameter of the holes.

MODE OF OPERATION

On removing the shutter, one side of the plate investigated—say, the lamp-black one—is exposed to the sun. The rise in temperature is indicated by a galvanometer which measures the current generated by the thermocouple.

The plate is heated by the radiation until its temperature exceeds a certain value θ_0, which is determined by the cooling curve of the apparatus which will be explained later. A few seconds after θ_0 is reached, the shutter is closed. As the temperature decreases along the cooling curve to θ_0, the time t'_0 is recorded and the actual measurements begin.

At the end of a certain fixed time interval Δt (in this case, ninety seconds) the temperature θ_1 of the plate is noted. The cooling is allowed to continue for a few seconds after reaching this temperature, the instrument then being rotated by 180° and the other shutter opened so that the test side of the plate is now facing the sun. The temperature now commences to rise and when it again reaches θ_1 the time t'_1 is recorded, and after the fixed time interval, Δt, the temperature θ_2 is noted. This heating proceeds beyond θ_2 for a few seconds, until—by closing the shutter—a new cooling-period begins. In a similar manner the temperature θ_3 is again measured ninety seconds after reaching θ_2 along the cooling curve. This cooling curve is followed by a heating curve through the exposure of the lamp-blacked face to the sun. The heating and cooling cycles are continued and similar time and temperature measurements are recorded by the observer. The general scheme is summarized by Fig. 2 and the following formulae:

$$\theta(t'_n) = \theta(t_n) = \theta_n$$
$$t_{n+1} - t'_n = \Delta t$$

The value of $(t'_n - t_n)$ is not critical and it is in general about ten seconds. As can be seen from Guild's paper, the ratio

$$\frac{(\theta_{4k-4} - \theta_{4k-3}) + 2(\theta_{4k-2} - \theta_{4k-3}) + (\theta_{4k-2} - \theta_{4k-1})}{(\theta_{4k-2} - \theta_{4k-1}) + 2(\theta_{4k} - \theta_{4k-1}) + (\theta_{4k} - \theta_{4k+1})} = R$$

is approximately equal to the ratio of the heat absorbed by the respective faces of the plate. If the radiation intensity falling on the two sides of the plate is equal, this ratio, therefore, is that of absorptivities of the two sides of the plate.

RELIABILITY OF RESULTS

The statistical errors in the instrument are quite sn provided measurements are made during the middle hou a clear day and one avoids strong winds, the results on a g sample repeat to within 1% so that the average of a measurements can be relied upon to a small fraction of This repeatability was found even when the perforated p "diaphragms" were varied by ±20% in transmission ra

The systematic errors also appear to be very small ov

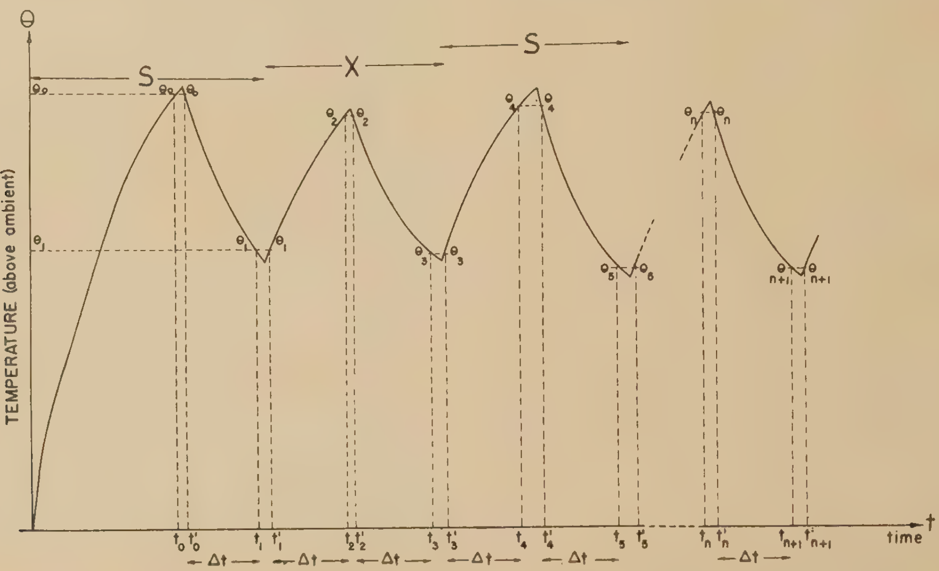


Fig. 2. Schedule of temperature-time cycles. (*S*, standard surface; *X*, test surface)

The degree of approximation is good—as shown by Guild—if two conditions are fulfilled.

(1) $\theta_{4k} = \theta_{4k+4}$, i.e. the heating and cooling curves of each side are retraced periodically. If the instrument is subjected to a large number of heating and cooling curves, a stationary state is established and this condition is fulfilled automatically, independently of the initial temperature θ_0. However, as shown by Guild, it is sufficient to choose θ_0 as the value reached t_0 seconds after initially opening the shutter, where t_0 is given by

$$t_0 = \Delta t \frac{\log [1 + (1/c)]}{\log (1/c)}$$

where c is a measure of the cooling rate equal to θ_1/θ_0 measured in any trial cooling curve. The time t_0 need not be very accurately determined.

(2) The ratio of the absorbed heat quantities should be close to unity. If this ratio does not depart more than 10% from unity, the systematic error introduced can be shown to be less than 1%. In order, therefore, to be able to measure absorptivities considerably less than that of the standard black, the perforated plates were used as calibrated diaphragms for reducing the solar intensity when falling on the standard black. Thus a small number of such plates with different sized holes was sufficient to ensure that the product of entering solar intensity and the absorptivity could be made equal to within 10% for both sides of the test plate.

The reduction ratio of solar intensity by the perforated plates is determined by measuring the hole areas and this ratio is used in computing the absorptivity when the ratio of the absorbed heats has been determined by the experiment:

$$\frac{\text{absorptivity of sample}}{\text{absorptivity of standard}} = \frac{R}{\text{reduction ratio of perforated plates}}$$

to the symmetrical nature of the instrument and of its o tion. From the experience of Guild it would seem that error introduced due to the different forms of heating (i.e one case the disk is heated through a layer of lamp-bl whilst, when reversed, it is heated directly) is very sm The largest source of uncertainty in the results would app to be apportioning the correct absorption coefficient to standard lamp-black, which is known to be over 0·95. order to arrive at as close a value as possible for this quant a plate was prepared in which one side was grooved or milling machine in two directions at right angles to cover plate with pyramidal impressions. The other side smooth. Both sides were then blackened and the groo side taken as having an absorption coefficient of 0·99.

It should be noted that the instrument, in its present for measures absorptivities for normal incidence of solar radiat which has passed through a sheet of glass. (Future moc will have the glass window set at an angle to avoid inter reflexions which can cause small errors.)

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of Messrs. Davidoff and M. Fried in carrying out numerous tests a to Mr. Y. Brada for helpful discussion. Leave was gran to one of us (I.T.S.) by the Hebrew University, Jerusale to take part in this work.

REFERENCES

(1) Tabor, H. *Bull. Res. Counc. Israel A*, **5**, pp. 119–1 (1955).
(2) Callendar, H. L. *Proc. Phys. Soc.* [*London*], **23**, pp. 1- (1910).
(3) Guild, J. *Proc. Roy. Soc., A*, **161**, pp. 1–38 (1937).
(4) Abbot, C. G. *Smithson Misc. Coll.*, **56**, No. 19 (1911).

Laboratory and workshop notes

A d.c. arc chamber for radioactive materials

y F. T. Birks, B.Sc., A.R.I.C., and R. P. Thorne, .Sc., A.I.M., A.Inst.P.,* Atomic Energy Research Establishment, Harwell, Berkshire

[*Note received* 21 *December*, 1955]

e a.c. spark is normally used for the analysis of radioactive terials, but it is sometimes necessary to use the d.c. arc order to obtain greater sensitivity of detection for im- ities. The d.c. arc spectrum is also used in comparison h the a.c. spark spectrum to assist in the interpretation of excitation states of the atoms involved.

The chamber that is used to contain the arc must be large ugh to prevent undue heating of the interior. In contrast the spark chamber designs, the electrical insulation pro- ties are of secondary importance to the need for dissipating intense heat that is radiated from the arc. Large amounts active material may be arced at one time, so an efficient ne extract must be provided, and it is desirable to have a ond container in order to confine any activity that should k out. The air is best extracted from the top of the mber since the flow is then assisted by the natural rise of air heated by the arc.

An early design by Todd(1) employed a simple thin metal about 6 in. diameter and 8 in. high. An air extract to a er was provided through a large cone placed over the open of the arc chamber, while air admittance holes in the es allowed a positive flow through the chamber. The tem was satisfactory for certain β- and γ-emitters such as P and ^{131}I, but was a poor container for the residual activity er the extract was shut off. Decontamination was achieved using three such containers in rotation and allowing a table rest time for the activity on each to decay.

A chamber better suited to α-emitters was used by llieson,(2) who employed as a basis a design by Conway d Moore,(3) but this suffered from the disadvantage that a ge area had to be opened to the atmosphere when the ctrodes were changed and no dry box to contain it was ailable at the time.

The present design was originated by Thorne after dis- ssion with C.I. Windscale and modifications were made by rks after experience with its use for α-emitters.

A general view of the arc chamber is shown in Fig. 1. It nsists of a synthetic-resin fabric body with large, screwed, d caps which hold the electrodes, and a base plate arranged that the whole apparatus can be rotated about the vertical is. The weight is kept low by making the metal parts of minium alloy, which has the additional advantage of good at conductivity.

The chamber fits directly on to a standard Hilger optical r to give constant optical alinement. The vertical adjust- ent of the electrodes is obtained by screwing the large end ps in or out, the total movement available at each electrode ing about ¾ in. The electrode supports are held by collets the centre of the screwed caps, and consist of ¼ in. diameter aphite having a ⅛ in. diameter graphite pedestal on to ich short lengths of high purity graphite electrode are ced. The upper electrode is usually a short length of n. diameter graphite. To change the electrodes access is de through a plug door in the side of the resin chamber, the apparatus first being rotated about its vertical axis to a convenient position. Electrical connexion (d.c.) is made from brass terminals attached to the end of each of the collets. The d.c. arc is struck by means of a spark from a high-frequency initiator circuit.(4)

The extract is taken from a tapered hole in the resin chamber by a $\frac{7}{16}$ in. outside diameter flexible polyvinyl chloride tube to a filter system. An air inlet flow is provided through a ⅛ in. deep channel to the interior cut in the top of the door.

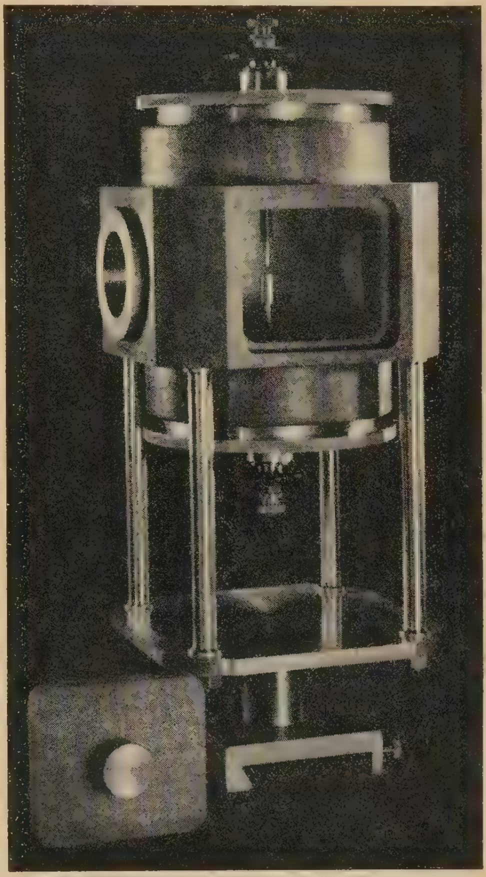


Fig. 1. General view of arc chamber

The chamber was first used in the open laboratory without a secondary container, but samples had then to be changed by carrying the whole apparatus to a fume cupboard. Subsequently it was used inside a dry box with the external optics described by Birks.(5)

Decontamination from accumulated large amounts of α-activity is carried out by swabbing the interior surfaces with moistened paper tissue. Any film that deposits on the quartz windows is removed with moistened lens tissue. These deposits give rise to an objectionable level of background activity when the material arced emits much β- or γ-radiation. In such cases a greater air flow through the chamber must be provided so that most of the activity is carried on to the filters.

The main body *A*, Fig. 2, is machined from a solid cube, 6¼ in. edge, of Vole brand Tufnol. Threads are cut in the ends to take the Dural screwed caps *B*, and in the sides to take the retaining rings for the 2 in. diameter quartz windows. The door *C* is made a close fit in the body and no hinge or retaining catch is then necessary.

---

* Now at United Kingdom Atomic Energy Authority, Capen- rst, Cheshire.

The main body is supported above the Dural mounting plate by four Dural pillars. These are insulated from contact with the copper braid electrical lead by covering with polyvinyl chloride tubes split lengthwise. A brass pin attached to the mounting plate is made a running fit in a hole in the stand which fits on the optical bar, but it can be locked in any position with a clamp screw.

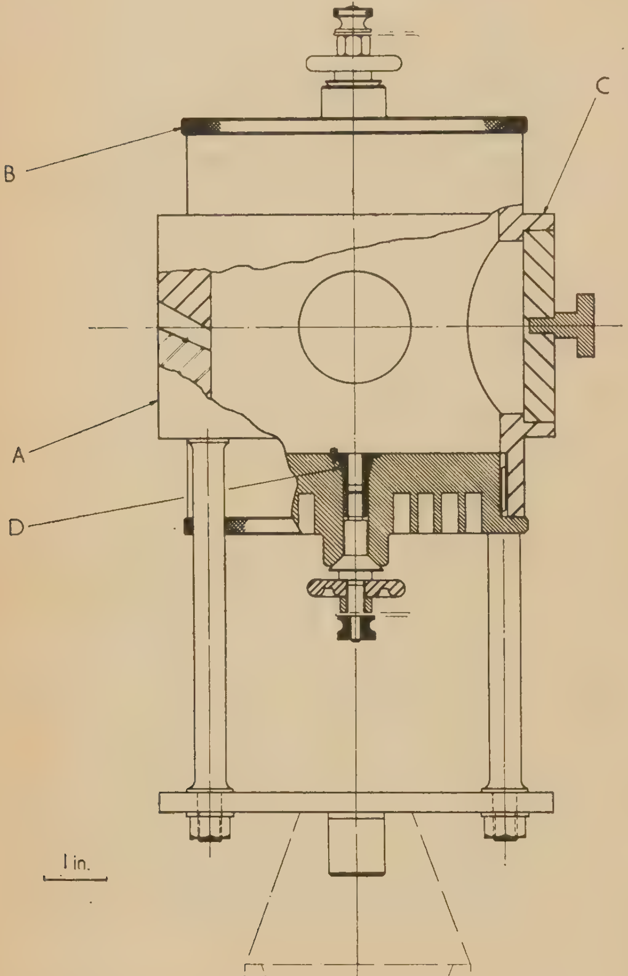


Fig. 2. Part-sectional side view of arc chamber

The collets, *D*, are made to hold ¼ in. diameter graphite but other sizes can be used as required. The screwed caps, *B*, each have four channels cut ¼ in. wide and ⅝ in. deep to assist the cooling and also to reduce the weight.

The authors thank the Director, Atomic Energy Research Establishment, Harwell, for permission to publish this paper.

REFERENCES

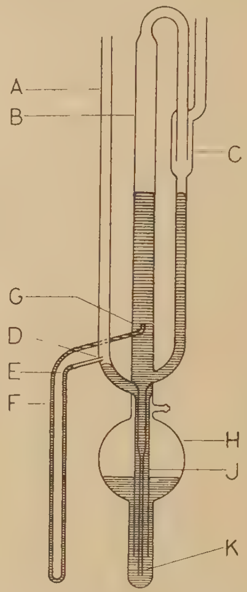
(1) Todd, H. J. Unpublished work at A.E.R.E., Harwell.
(2) Gillieson, A. H. Unpublished work at A.E.R.E., Harwell.
(3) Conway, J. G., and Moore, N. F. *Analyt. Chem.*, **24,** p. 463 (1952).
(4) Brockman, F. G., and Hochgesang, F. P. *Ind*
Engng Chem., Anal. Ed., **14,** p.796 (1942).
(5) Birks, F. T. A.E.R.E. Chemistry Report 1631 (19
Spectrochimica Acta, to be published.

A gas introductor for a vacuum system

By H. A. Wyllie, M.Sc., Imperial Chemical Industrie
of Australia and New Zealand Ltd., Melbourn
Australia

[*Note received* 10 *February*, 1956]

The introduction of small, measured amounts of gas int
vacuum system may be achieved by the micro-introducto
Mignolet* in which the gas comes into contact with g
and mercury only. If one merely desires to introduce roug
estimated amounts of gas, the more compact device show
the figure and described below may be used.



Gas introductor for a vacuum system

The tube *A*, of 12 mm internal diameter, leads to the g
reservoir. The tube *B*, of 22 mm diameter, is connected
the vacuum system through the cut-off *C*. When the pressu
of the air over the mercury in the 500 cm^3 flask *H* is increas
mercury flows into *B* through the tube *K*. The lower 18
of this inner tube consists of 1 mm capillary tubing whi
restricts the rate of flow. The mercury flows into *A* throu
the annular space between the tubes *J* and *K*. The tube
is connected to the tube *B* by the 1·6 mm diameter capill
tubing *DEFG*. In the actual introductor the capillary U-tu
EF is situated at the back of the flask *H* with the limb *F*
the right of limb *E* and the capillary tube entering *B*, at
from the back.

Suppose that the air pressure in the flask *H* has be
adjusted to bring the mercury meniscus to the position in *L*
shown in the figure. If the air pressure in *H* is now increas
at the rate of about 1 cm/s the mercury in *A* rises above
cutting off a bubble of gas in *DE*. Because the mercury
rising more rapidly in *A* than in *B*, the bubble is pushed alo
to the end *G* of the capillary and rises up through the mercu
in tube *B*. The top end of *B* is 50 cm above the lower e

---

* Mignolet, J. C. P. *J. Sci. Instrum.*, **30,** p. 15 (1953).

C. This allows plenty of room for the splashing which curs when the bubbles burst.

Some small bubbles remain sticking to the tube *B* below surface of the mercury. There is a possibility that these iy rise later. If this would be inconvenient the mercury n be raised to close the cut-off *C*. When the pressure in gas reservoir and the length of the bubble cut off in *DE* ceed certain values, the introduction of the bubble requires air pressure in flask *H* to be raised above one atmosphere. is is done by means of a foot pump. When the vacuum stem is opened to the atmosphere, the capillary U-tube *EF* mains partly filled with mercury and thus continues to late the reservoir.

The tube *K* and the U-tube *EF* should extend below the ttom end of tube *J*. This will prevent a violent rush of gas to the vacuum system, should the air pressure in flask *H* accidentally reduced too far. If the mercury surface has me down between tubes *J* and *K* to the bottom of *J*, a bsequent increase in air pressure will simultaneously crease the gas pressure in *A*, and, unless the pressure is creased slowly, the meniscus in limb *E* will first of all be rced downwards. However, it will not reach the bottom the U-tube if the latter extends far enough below tube *J*.

The flask *H* is supported by plaster of Paris in a cylindrical ainless steel container, through the bottom of which the ng well protrudes. The container stands on three legs hich are screwed to the bench.

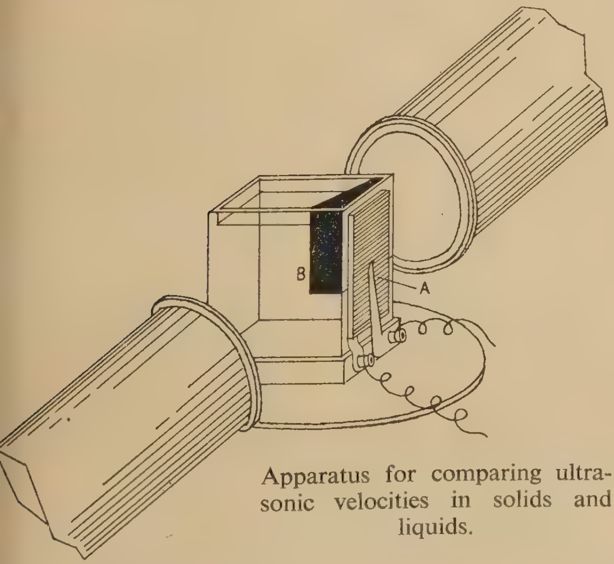
The author wishes to thank Mr. E. F. Dawes for carrying it the glass-blowing.

method for comparing ultrasonic velocities in solids and liquids using a spectrometer

By G. M. Śreekantath, M.A., and A. O. Mathai, M.Sc.,
University College, Trivandrum, S. India

[*Note received* 5 *September*, 1955]

is known that unlike the conditions which apply in an dinary light grating, the diffraction pattern produced by Debye–Sears' optical cell is clear and visible only when the ht wave front is normal to the sound beam. This fact can taken advantage of for the accurate determination of trasonic velocities.



Apparatus for comparing ultrasonic velocities in solids and liquids.

The sound waves proceeding from the piezoelectric source *A* (see figure) pass through the wall of the glass cell. The upper portion of this beam then passes at normal incidence through a thin right-angled prism *B* of the chosen solid to the liquid medium beyond, while the lower portion proceeds straight into the liquid, so that, while at lower layers the sound beam proceeds undeviated, at layers above the beam gets deviated by refraction from the prism to the liquid. To avoid confusion, one of these portions may be masked when the other is being observed. The correct alinement in each case corresponds to maximum intensity of the diffraction bands as indicated by the feeblest order. The angular separation between these two positions, read directly from the spectrometer, gives the deviation produced by refraction from prism to liquid, from which the ratio of the ultrasonic velocities in the two media is obtained.

The small angular separation between the diffraction bands is a limitation to the accuracy of the ordinary diffraction method for the comparison of ultrasonic velocities, while in the present case the observed angular deviation, which depends on the angle of the prism, can have, in many cases, considerably larger values. Hence the accuracy is correspondingly higher. The method is applicable to solids and liquids alike, of which the former need not be transparent.

A modified flap-type vacuum valve

By H. M. Buck, Department of Supply, Melbourne, Australia

[*Note received* 15 *November*, 1955]

The elementary flap-type vacuum valve consisting of a valve plate attached by an arm to a rotatable shaft (the axis of which lies to one side of the normal projection of the valve aperture and parallel to the plane of the aperture) is mechanically simple and offers the minimum restriction to gas flow. It suffers, however, from the disability that considerable force is required to open it against pressure. This is particularly so when the valve is placed in the system in the preferred aspect where the pressure forces the valve against its seating.

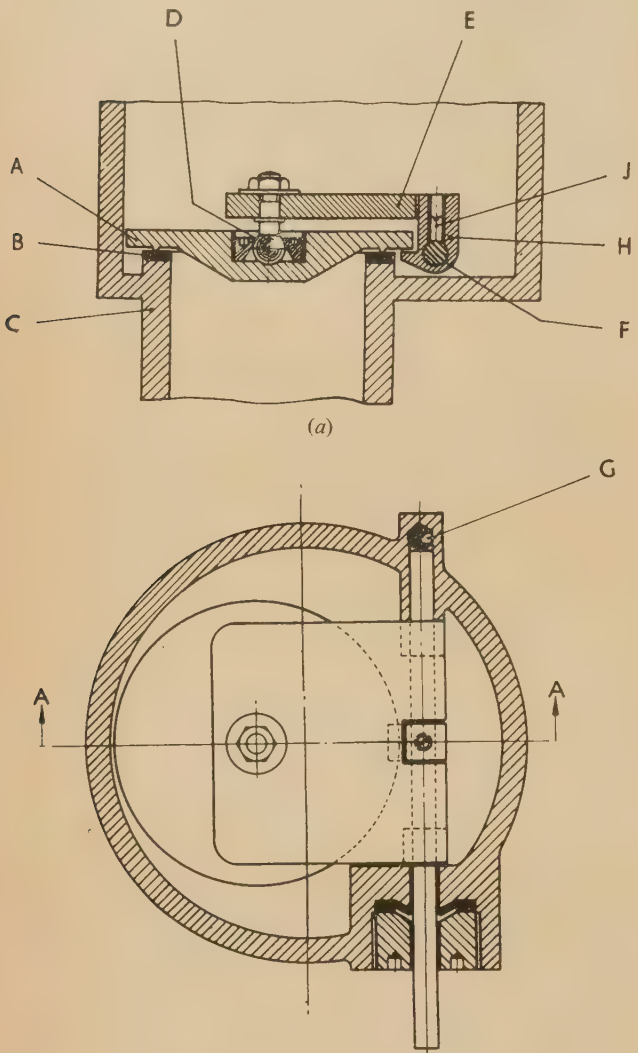
Providing that this type of valve can be cracked, the pressure difference on the faces of the valve plate (even in most pumped systems) will be quickly reduced to a value where further opening of the valve becomes relatively easy.

The design shown in Figs. 1 and 2 was developed by the author and has been used on systems involving opening against atmospheric pressure. The action on opening is in two stages, consisting of cracking and partial opening followed by direct lift to the fully opened position.

Referring to Fig. 1, the valve plate *A*, which seals against a neoprene washer *B* secured in a channel machined in the body *C*, is provided with one or more smooth pressure ridges and is attached, at its centre, to the ball-ended peg *D* about which it is free to swivel. The peg *D* is carried by an arm *E* which terminates in a forked end composed of two lugs bored to be a free running fit on the actuating shaft *F*, to which the arm is not directly secured. This shaft rotates in bearings in the body and passes through a Wilson seal for external operation of the valve. The thrust due to atmospheric pressure on the end of the shaft is taken on a ball *G*.

A cam *H*, which is secured to the shaft between the lugs of the arm *E* by a grub screw *J*, is provided with a toe piece which is brought under the edge of the valve plate. It is also provided with a heel piece extending between the lugs into the forked end of the arm.

On rotation of the shaft, the toe of the cam tilts and lifts the valve plate from its seating on one side, thus "cracking" the valve. Further rotation of the shaft first carries the edge of the valve plate into contact with the arm, and then lifts the arm and the valve plate as in normal flap valves.



(a)

(b)

Fig. 1. (*a*) Sectional elevation on line *A–A*
(*b*) Sectional plan

In the initial cracking of the valve, the cam lifts less than one half of the total load comprising the weight of the valve plate and thrust due to pressure. Further, the point of application of the force exerted by the toe of the cam can be kept to a relatively small radial distance from the axis of the shaft, leading to a considerable reduction in torque required on the operating shaft compared with the conventional flap valve.

If a further reduction in operating torque is required (as on very large diameter flap valves) the arrangement shown in Fig. 2 may be used. In this figure the cam *K* is a simple eccentric, a constant rise or some similar type cam, and acts on an extension beam *L* secured to the valve plate. This design allows the mechanical advantage to be still further increased for cracking and initial opening. The cam also serve as a means of locking the valve in the cra position.

In both designs, thrust for the initial sealing of the on closing is applied through the heel of the cam w contacts the arm.

A degree of scuffing of the valve plate on the neop washer cannot be avoided, but no trouble from this sc

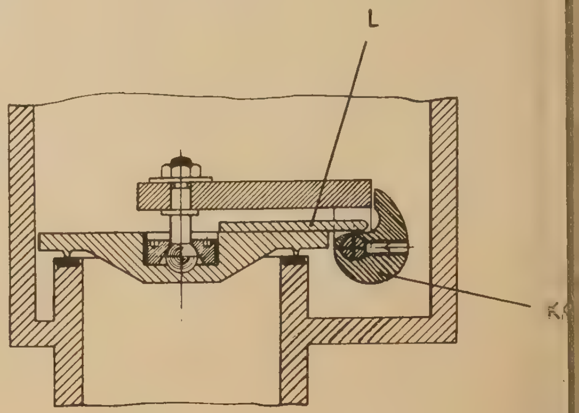


Fig. 2. Alternative construction

has been experienced. In an endeavour to reduce the amo of scuffing, the centre of the ball-ended support peg *D* been arranged in approximately the same plane as pressure ridges. It is essential, of course, that the pres ridges of the valve plate be smoothly finished.

The valve has been used in all positions and on sys involving pumping to pressures below 5 × 10^{-5} mm mercury with complete success.

This note is published with the permission of the C Scientist, Department of Supply, Australia.

Adhesives for galvanometer mirrors

By Norah W. Sullivan, National Physical Laborator
Teddington, Middlesex

[*Note received* 21 *March*, 1956]

For certain ocean-bed recordings, galvanometers are emplo in which a mirror is used to produce an image of a spo light on a continuously moving film. On occasions, galva meters which have performed perfectly in the laboratory h given considerably inferior records when in submarine This has been attributed to distortion of the mirror due the effect of sudden changes of temperature on the adhe used for attaching the galvanometer mirror to its supp A survey has, therefore, been made of a number of adhesi to find one that does not suffer from this disadvantage.

A number of galvanometer mirrors were attached supports with twenty-two different adhesives. These mirr were 6 mm square and 0·15 mm thick and were checked optical quality before being mounted. The supports w rods of either Tufnol or Duralumin. The mirrors w attached by a minimum of adhesive and left for twenty-f hours at the usual room temperature of about 20° C. optical system was employed in which the mirror under was used to produce an image of a circular aperture $1\frac{1}{2}$ mm diameter. At the same time, an image of the sa

e was obtained from a mirror of known flatness, and
:orded together with the test spot on 35 mm film. The
lexion from the flat mirror was used as a standard of
mparison.

The mirrors on their supports, together with the test
uipment, were placed in a room, the temperature of which
s controlled at 2° C. After an interval of five minutes the
st records were made, the whole operation taking a few
nutes. After an interval of twenty-four hours the records
re repeated. The same procedure was adopted at a
nperature of 20° C and again at 37° C. In cases where
adhesive had given a good performance the reflexion from
mirror under test was seen to be as good as the reflexion
m the flat mirror. Where distortion of the mirror occurred,
reflexion from the mirror under test was drawn out into
ellipse with flare at the edges, the elongation being of the
der of 100%. Very slight distortion resulting in an
ngation of less than 15% occasionally occurred and was
cepted as satisfactory.

Of the twenty-two adhesives tested the following were
und to be satisfactory as regards adhesion and freedom
m mirror distortion: Reid and Sigrist type VII adhesive;
nada balsam; Bedacryl; rubber solution; shellac in alcohol;
eswax and resin; pitch; Apiezon wax "W" in benzene;
icone F. 4033; Araldite 103.

On occasions, even with some of these adhesives, slight
stortion of the mirror was evident, the notable exception
ing Reid and Sigrist type VII adhesive which gave a con-
tently good performance at rapidly changing temperatures
d over a wide range. This adhesive has since been used
tisfactorily in practice. Canada balsam and silicone F. 4033,
nile not quite as good as the Reid and Sigrist type VII
lhesive, were reasonably satisfactory.

Acknowledgement is made to Mr. A. Jackson, under whose
iidance this work was done.

The work described above has been carried out as part of
e research programme of the National Physical Laboratory
id this note is published by permission of the Director.

A microwave amplitude stabilizer

By S. J. Fray and M. F. Kimmitt, B.A.Sc., Radar
Research Establishment, Malvern, Worcs.

[*Note received* 27 *February*, 1956]

icrowave experiments employing resonant cavities are often
ore easily performed when the frequency of the klystron
nerator is stabilized, as, for example, by a feedback voltage
ntrol on the reflector. Such systems tend to induce
ictuations in the power output. This note describes a
mple, long term, amplitude stabilizer, with a ferrite modu-
tor as the controlling unit, which has been used successfully
a frequency of 35 000 Mc/s.

The system is shown schematically in Fig. 1. A rectified
gnal, proportional to the power in the main guide, is obtained
om the crystal detector D, and causes a potential drop across
. This is backed-off by the potentiometer circuit BR_1R_2
that only fluctuations of potential about a fixed level are
esented to the d.c. amplifier A. The amplifier is a Sunvic
pe DCA1, with a time constant of 0·1 s, and the output
rrent flows through the solenoid to produce a longitudinal
agnetic field. The ferrite rod is of Mullard B2 material,
out 1 in. in length and $\frac{1}{16}$ in. in diameter and is supported
a cylindrical waveguide propagating the Te_{11} mode.
Lossy vanes are inserted in the guide such that the resulting Faraday rotation of the plane of polarization causes variation in attenuation.

The amplifier was used on its most sensitive scale giving a maximum output current through the ferrite coil of ±5 mA for a change of crystal current of about 0·25 μA. A bias field, from the permanent magnet M, was arranged so that small currents through the coil had a maximum effect on the attenuation. Fig. 2 gives the current attenuation characteristic of the ferrite and coil with the permanent magnet in position.

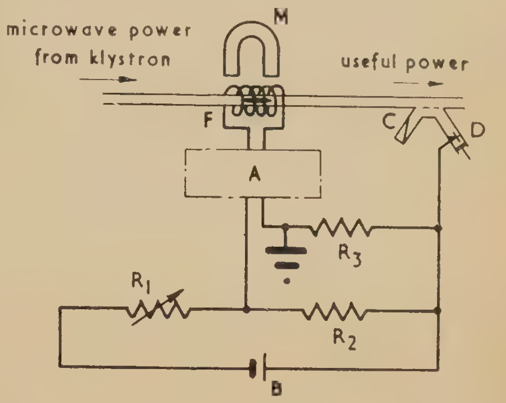


Fig. 1. Schematic diagram of amplitude stabilizer

A = amplifier
B = battery
C = directional coupler
D = crystal detector
F = ferrite modulator
M = permanent magnet
R_1 = decade resistance
R_2 = 10 Ω
R_3 = 1000 Ω

The sensitivity of the system is a function of the detector current. When the crystal was passing 93 μA the crystal sensitivity was 24 μA/dB giving an overall stabilization factor of about 140. The system has proved capable of correcting for input variations of microwave power up to ±1·5 dB (limited by the amplifier), the stability of the output power being within about 0·01 dB.

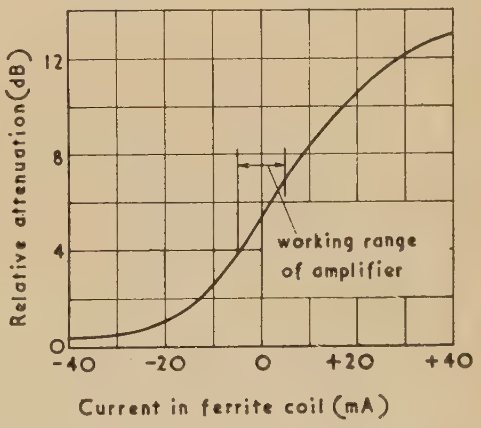


Fig. 2. Current attenuation characteristics of the ferrite and coil with the permanent magnet in position

The authors are indebted to Dr. A. F. Harvey, who suggested the use of the ferrite modulator, and Mr. D. A. H. Brown for helpful discussion and advice. Acknowledgement is made to the Controller, H.M. Stationery Office, for permission to publish this note.

Correspondence

A simple bridge circuit for the accurate measurement of pulse impedance

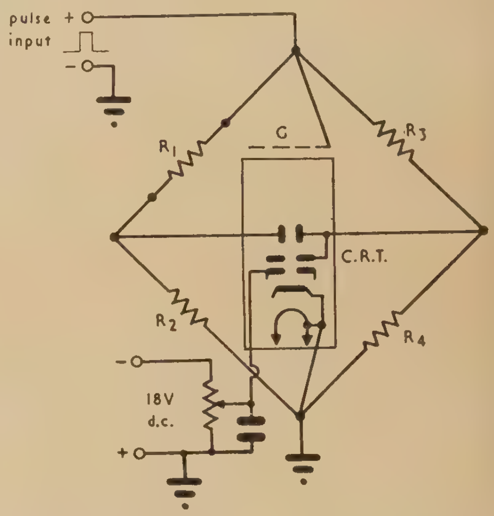
The most convenient and accurate techniques for the measurement of electrical impedance are those which employ a bridge circuit, yet difficulties are apt to arise if it is required that the bridge voltage shall be applied in the form of repetitive pulses lasting a microsecond or less, as may be necessary, for instance, in the measurement of the resistivity of semiconductors at high field strengths, or of the surge impedance of transmission lines. These difficulties stem from the difficulty of constructing either a pulse generator or a null detector, each of whose terminals has an acceptably high impedance to earth and which will accept a pulse voltage to earth which is large compared with the out-of-balance signal. The difficulties are somewhat increased if it is required, in addition, that the voltage across the unknown impedance shall be variable up to several kilovolts. It is the purpose of the present note to describe a simple and sufficiently sensitive null detector having the required properties.

The deflecting plates of a cathode-ray tube have the necessary impedance to earth and the property of producing a beam deflexion which depends only on the *difference* of potential between them, but the application of any appreciable voltage between the plates and the final anode of the tube results in severe defocusing of the beam. The impedance to earth of this anode is, however, usually quite high, so that it may be connected directly to one of the deflecting plates, as shown in the figure. Provided that the bridge voltage is high enough to operate the tube, the following advantages are obtained:

(i) no high-tension supply for the tube is required;
(ii) since the beam current flows only during the energizing pulse, no time base is necessary to provide time discrimination;
(iii) the display on the screen consists of a stationary spot which is much brighter, for a given beam current, than the conventional time-base display;
(iv) the sensitivity of the detector, in terms of spot deflexion for a given degree of unbalance in the bridge, is independent of the bridge voltage. The energizing pulse need not, therefore, be more than very approximately rectangular in shape;
(v) the only components required, in addition to the cathode-ray tube itself, are the sources of heater and grid-bias voltages.

The one-inch cathode-ray tube type 1CP1 (by Electronic Tubes Ltd.) is particularly suitable for use in this circuit, as it is extremely compact and has an electron gun which requires no additional source of voltage for focusing purposes. There should be no difficulty in using other types; the focusing anode would then be connected to a tapping on R_4. The type 1CP1 tube used in a bridge having a ratio R_4/R_3 equal to unity gives a spot deflexion of about 0·5 mm for an error of 1% in balancing the bridge. In practice, the measured random error in setting the spot to a fiducial mark, viewed by a low-power magnifying lens, is about 0·2%.

The fluorescent spot produced by the use of a pulsed anode voltage is, unless further precautions are taken, disappointingly dim and ill-focused. This difficulty apparently results from the inability of the beam to charge the fluorescent screen up to the anode voltage in the short time available, but be completely overcome by fixing to the outside of the sc a wire gauze (*G* in the figure) which is connected to the an The capacity between the gauze and the inner surface ensures that the potential of the latter follows that of anode. A further improvement results if the gauze is nected, not to the anode, but to the input pulse generato shown. A substantial degree of post-deflexion acceleratio thus obtained.



Bridge circuit for the accurate measurement of pul impedance. *X*-plates (not shown) of cathode-ray tube a connected to anode

Typical circuit values: *CRT*, 1CP1; R_1, unknown arm; variable arm; R_3, R_4, 100 Ω, ¾ W high-stability carbo *G*, gauze electrode.
Pulse amplitude and duration, 400–2000 V, 0·5 μs.

Certain precautions must also be observed in the choic resistors for the arms of the bridge. Wire-wound resistors potentiometer are, of course, too reactive, while the resista of the ordinary carbon type cannot be relied upon to rem constant at high voltages. By comparing the parallel c bination of a number of resistors against the surge impeda of a length of coaxial cable (which must, of course, independent of voltage), it has been shown that ¾ W h stability carbon resistors having values near 680 Ω vary less than 0·25% over the voltage range between 200 800 V. The variable arm of the bridge is best compo mainly of high-stability resistors with a carbon potentiom arranged to give only a fine adjustment, so that the effec its voltage-sensitivity is sufficiently reduced.

It may be remarked that, since the bridge can be used 0·1 μs pulses, the characteristic impedance of a length coaxial cable only ten metres long can be measured to th significant figures, and the result is quite unaffected by termination of the cable.

This note is published by permission of the Control H.M. Stationery Office.

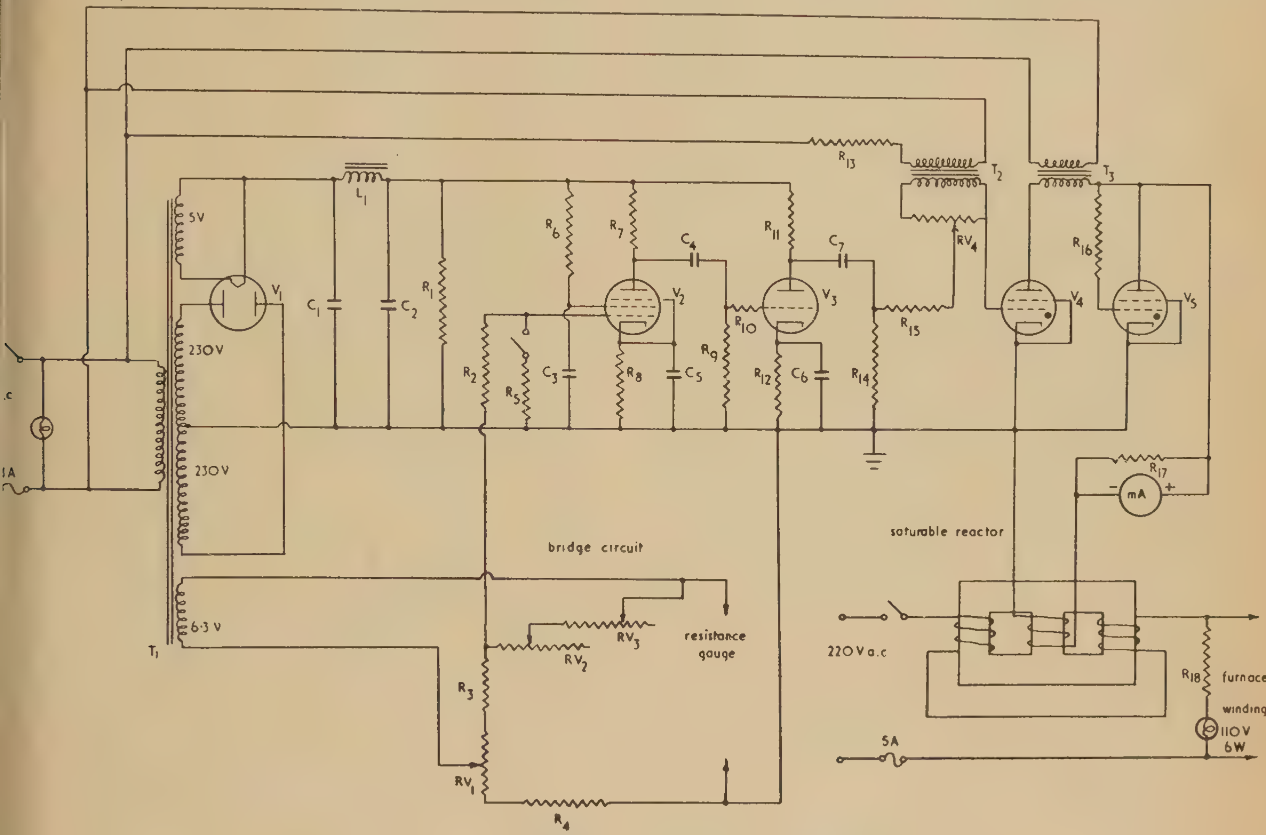
Radar Research Establishment,
Great Malvern,
Worcs.

J. B. Gun

Temperature controller for an electric furnace

roportioning temperature controller for automatically lating the temperature of an electric furnace has been ribed by Eubank.* In this controller, a resistance nometer forms one arm of a Wheatstone bridge; the ge unbalance voltage is amplified and used for the phase rol of a thyratron.† The thyratron current in turn trols a saturable reactor in the furnace heating circuit. setting of the regulator is somewhat complicated, how-, and the present controller was designed as a more ble instrument for an application in which it was necessary ring the furnace quickly to widely separated temperatures. n be set by a direct reading dial to control at any tempera- between 50 and 1000° C. This calibration depends on resistance gauge, but not on the resistance of the furnace ding. An adjustment can be made to accommodate to the constant of the furnace. In the event of gauge burn-out furnace will shut off. The whole controller, including the rable reactor, is mounted on a 17 × 11 × 2 in. chassis.

he complete circuit diagram is shown in the figure. The ge is designed for a resistance gauge wound non-ictively of 15 ft of platinum wire 0·005 in. in diameter. room temperature resistance of the gauge is 40 Ω; at)° C the resistance increases to 140 Ω. The variable arm 100 Ω helical potentiometer, model A by Helipot Corp.



Complete circuit diagram of temperature controller

= 25 kΩ, 10 W
= 1 MΩ
, R_4 = 80 Ω
= 47 kΩ
= 1 MΩ
= 270 kΩ

R_8 = 1·1 kΩ
R_9, R_{10} = 470 kΩ
R_{11} = 270 kΩ
R_{12} = 4·7 kΩ
R_{13} = 6·9 kΩ
R_{14} = 1 MΩ

R_{15} = 300 kΩ
R_{16} = 1 MΩ
R_{17} = 10 Ω
R_{18} = 2 kΩ, 10 W
RV_1, RV_2 = 50 Ω

RV_3 = 100 Ω helical
RV_4 = 250 kΩ
C_1, C_2 = 20 μF
C_3, C_4 = 0·1 μF
C_5, C_6 = 50 μF

C_7 = 0·06 μF
V_1 = 5U4G
V_2 = 6SJ7
V_3 = 6SF5
V_4, V_5 = 2050 thyratron

T_1 = power transformer
T_2 = input transformer, 20 V, a.c.
T_3 = power transformer, 430 V, a.c.
L_1 = 10H
mA = 0–50 mA

In order to provide adjustment to make the potentiometer dial direct reading, two 50 Ω potentiometers are incorporated into the bridge. An attenuator switch is provided in the amplifier input. In operation, the switch is left closed while the control temperature is being approached. The resulting attenuation of the signal prevents overshooting of the furnace. When the control temperature is reached, the switch is opened, providing full sensitivity. The amount of quadrature voltage which is added to the amplified bridge output may be varied between 0 and 20 V, in order to adjust the proportioning range of the controller for the time constant of the furnace being controlled. The saturable reactor used (model 127-563-1 by Sorensen and Co., Connecticut) is suitable for a furnace winding of about 60 Ω. The furnace can be supplied from 110 V a.c., though the 220 V supply gives better control and faster approach to the control temperature.

The performance of the controller has been found satisfactory without regulation of the supply voltage. It will hold the furnace temperature constant within ±0·2° C over a period of hours, and within ±0·5° C over several days. In a test in which the controller supply voltage was changed by 10 V, the furnace temperature changed only 1·5° C. This 0·15° C/V variation with line voltage fluctuation could, of course, be eliminated by supplying the controller from a constant voltage transformer.

Dartmouth College,
Hanover,
New Hampshire, U.S.A.

R. W. CHRISTY

EUBANK, W. R. *Rev. Sci. Instrum.*, **21**, p. 845 (1950).
M.I.T. Staff. *Applied Electronics*, p. 313 (New York: John y and Sons, Inc., 1943).

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or imp products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Cable cleats. Evershed and Vignoles Ltd., Acton Lane Works, Chiswick, London, W.4.

The cleat illustrated in the figure has been designed to secure wires in electrical apparatus having large wiring circuits. It permits easy inspection and maintenance. Each cleat has five wire channels and any number of cleats can be mounted one on top of another by means of spring clips. An end plate clips on to the topmost cleat to secure the cables running through it.

A set of three cable cleats and end plate clipped together

Interference-filter reflectometer. Société d'Applications Photélectriques, 23 rue de Madrid, Paris. U.K. agents: J. F. Crosfield Ltd., 2 Elthorne Road, London, N.19.

The Chromameter, as this interference-filter reflectometer is called, is intended for spectral reflectance measurements on white and coloured surfaces and is a compromise between instruments designed for routine testing and spectrophotometers. It uses narrow-band interference filters in combination with a vacuum photocell and a two-stage d.c. amplifier. The filters isolate bands of 5 mμ in width from the visible spectrum: the number of filters and wavelengths of the transmission bands can be selected, e.g. twelve filters covering a transmission band from 435 to 675 $\mu\mu$. This number can be increased indefinitely.

The instrument consists of a main body and a colour measuring head (Fig. 1). The main body contains the galvanometer, power pack and second stage of the amplifier; while the measuring head contains the light source, filters, a type BG photoemissive cell with linear response and the first stage in the amplification. Specimens are illuminated at 45° and viewed normally, as recommended by the C.I.E., and stray light within the head is reduced to a negligible amount. A block of pressed magnesium carbonate, under the head, is used as the standard white. With this standard at *P* (Fig. 2) the sensitivity of the galvanometer is varied until a reading of 100% is attained. The percentage reflectances are then obtained, with the sample in position, for all waveler transmitted by the range of filters.

The interference filters alter appreciably for the first of their life, and they are not incorporated into the in ment before this age. It is claimed that they then re stable provided that they are kept at a temperature of bet 17–21° C and at a relative humidity of approximately

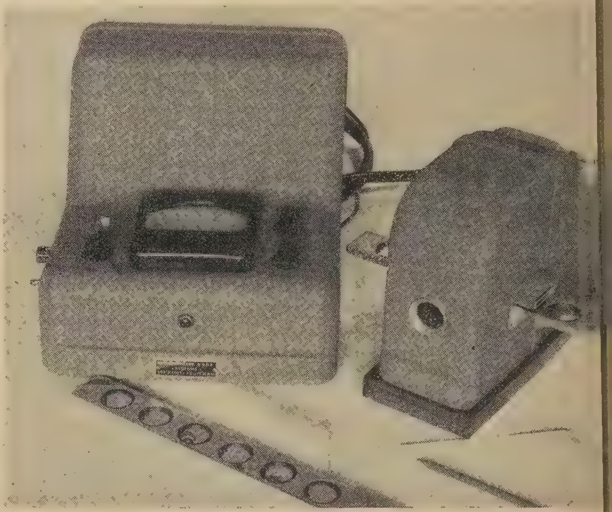


Fig. 1. The main body, colour measuring head ar interference filters of the reflectometer

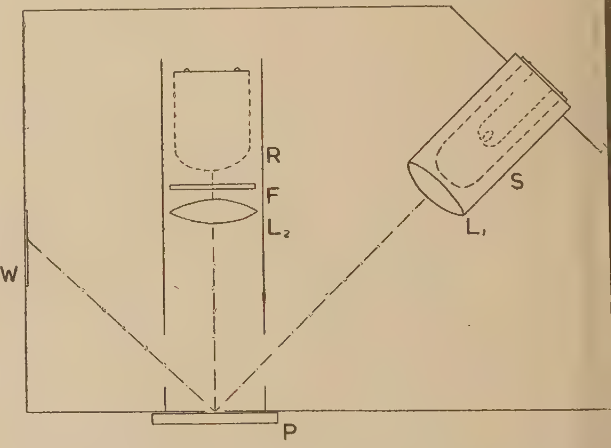


Fig. 2. The optical system of the measuring hea *L*, lens; *S*, lamphouse; *P*, sample; *R*, photocell; *W* viewing window; *F*, interference filter

Since the filters are interposed into the light beam afte has been reflected from the sample, the measurements gi fair indication of the appearance of fluorescent samples w illuminated by light of the same spectral composition as t used in the instrument. The colorimetry of fluoresc samples has not yet been standardized but it is known t their colour will vary with the ultra-violet content of the li under which they are viewed.

Notes and comments

tions to The Institute of Physics

ie following elections have been made by the Board of Institute of Physics.

llows: C. Davies, W. S. Elliott, G. De V. Gipps, H. G. rd, J. M. Valentine.

sociates: K. J. Bobin, P. F. Burden, J. A. Brand, K. G. , W. E. Carr, J. P. Carter, J. G. Clouston, M. V. Cowin, Croft, P. B. Curtis, G. E. Darwin, P. U. A. Grossman, . Harrison, H. D. Harwood, D. Hughes, I. MacPherson, McChesney, J. D. McKee, I. L. Muter, N. Ochert, A. C. son, J. V. Ramsay, G. H. Rees, J. R. Rowbotham, R. F. , A. M. Short, J. J. Singh, J. G. Speight, L. K. Street, I. Swindon, I. M. Templeton, D. A. Tidman, M. W. J. tt, A. H. Ward.

venty-six Graduates, six Students and two Subscribers also elected.

nt work at the National Physical Laboratory

e Report of the National Physical Laboratory for 1955 recently been published by H.M. Stationery Office. ng the many matters of interest to readers of this *Journal* ccounts of the new caesium standard of frequency and interval, and the work being done on the full-scale matic computing engine ACE. These and other shorter s of particular interest are summarized below under the es of the Divisions responsible.

rodynamics. The Laboratory has used polyester resin essfully for the insertion of surface-pressure leads in el wings and has found the process rapid and the finish ptionally smooth.

its investigations into the development of optical tech- es suitable for studying high-speed flows, the Division made a systematic series of experiments on the behaviour arious photographic emulsions at short exposures.

ontrol Mechanisms and Electronics. A steadily increasing t is being put into the manufacture of the full-scale ACE, that the Pilot Model has been relegated to the Science eum. The computer will use mercury delay lines cir- ting at 1·5 million pulses per second for its high-speed e. Twenty-four long delay lines, having a maximum ss time of 1 ms, will store a total of 768 words of 48 binary s. Another 20 short delay lines storing one, two or four ds each will have a total capacity of 40 words. In addition 00 words will be stored on magnetic drums with an ss time of less than 10 ms. The input sections of the puter will be able to read all 80 columns from each of Hollerith card readers simultaneously. The output on will contain two card punches, with the ability to ch all 80 columns simultaneously. Provision is being e for the addition of magnetic tape equipment.

n automatic graph plotter has been designed, which ates on data from punched cards, and will soon be in mercial production. A number of new designs have lted from the application of data reduction techniques to strial purposes, including the modification of a com- cial self-balancing recorder to record readings in a digital n on punched cards, or by typewriter.

ectricity. The first experimental model of an atomic- n standard of frequency and time interval is giving results precision never previously attained.

ie prototype consists of a caesium atomic-beam chamber rporating the focusing system developed by Rabi. tromagnetic waves generated by a highly stable oscillator of a frequency capable of very fine adjustment are fed into the chamber, and the frequency is observed at which the atoms show transitions between two ground-state energy levels, associated with the interaction between electronic and nuclear spins. This frequency, being characteristic of the structure of the caesium atom, serves as a primary reference standard for all measurements of frequency and time interval. Expressed in terms of the unit of time now generally accepted, the value of the frequency of the caesium standard is 9 192 631 850 c/s.

Some simplification of the experimental model with a possible improvement of accuracy will be attempted. A model with a longer beam chamber is contemplated, as well as a smaller one suitable for more general use.

The Division has constructed five 1 Ω standards having temperature coefficients of less than 1 in 10^6 over the range 15° C to 25° C, as well as a sub-divided megohm and a screened sub-divided 100 000 Ω standard of small time constant.

Metrology. A 72 kMc/s (wavelength = about 4 mm) microwave interferometer for the measurement of the velocity of "light" has been set up, and a 72 kMc/s refractometer was constructed to determine the refractive index in the neighbourhood of the interferometer. This has also been used to measure the refractive index of some gases, including oxygen and water vapour. These two determinations were of particular interest in showing a satisfactory agreement between theory and practice.

Two bore-measuring machines built on the principle of auto-collimation have shown a high degree of accuracy in service. The smaller one, now in commercial production, has maintained its accuracy at the level ±0·000 01 in. and has been trouble-free throughout the year. The accuracy of the larger machine, which extends the range of measurement up to 6 in., has not been investigated with quite as much detail but is known to be of the same order as that of the smaller machine.

Another item which has aroused considerable interest in industry is the apparatus developed for measuring fine wires, also based on the principle of auto-collimation. Thought is being given to the development of similar apparatus with a simpler arrangement and a lower accuracy of measurement than the present ±0·000 01 in.

A method has been devised to measure the progressive and periodic errors of a screw to an accuracy of a few millionths of an inch. The advancement was measured interferometrically when the screw was rotated through angular intervals measured by means of a calibrated steel polygon and an auto-collimator.

A design has been completed for commercial production of the pneumatic gauging apparatus for testing the flatness of photographic plates, which was briefly reported last year. The apparatus enables the plates to be rapidly inspected before use, to ascertain whether their flatness lies within prescribed limits. The plate is placed emulsion downwards, on three balls; six jets of air blow upwards against the emulsion at a pressure of less than $\frac{1}{2}$ Lb/in.^{2} The errors of flatness are shown directly by the levels of coloured water columns in six manometer tubes and are read on linear scales placed behind the tubes; the magnification is 2500 and the range covered ±0·0006 in. This apparatus essentially measures departures from a prescribed form and, with suitably designed gauging fixtures and standards of known error, could find uses in other fields of measurement.

Work is also progressing on the development of a prototype apparatus using the pneumatic gauging principle which will continuously measure the thickness of thin sheeting (e.g. cellulose acetate film) during production.

Physics. A development of importance during the year has been the use of a new method for the precise measurement of high pressures. This method applies the principle of similarity to the distortions under pressure of two piston-cylinder assemblies of the same dimensions but of materials having different elastic constants. As a result it is now possible to establish the effective areas of pressure balances to an accuracy of a few parts in 10^5 over a wide range of pressure. The method is being extended to cover higher pressure ranges.

New apparatus has been installed for normal temperature thermal conductivity tests on disks. The thermal conductivity values obtained will be used to calibrate a radial-flow apparatus constructed in glass and designed for tests on aggressive fluids. New determinations made on iridium and rhodium showed that the commonly accepted values were erroneous. Carbon deposits, prepared at the Royal Aircraft Establishment, were found to have a 40% higher thermal conductivity than copper at 50° C.

A newly-constructed boiling-point apparatus of pure aluminium is being used for experiments on the reproducibility of the boiling point of sulphur. The pressure under which the sulphur boils is controlled close to standard atmospheric pressure, and a short term reproducibility of reading of $\pm 0 \cdot 002°$ C is obtained. To find whether the long term stability, after prolonged or repeated boiling, is equally good, is the object of the investigation.

A programme of experimental heat treatments has been started in the hope of arriving at a means of producing mercury-in-glass thermometers sufficiently stable for the exacting needs of present-day industry.

The re-determination of equal loudness contours for pure tones has been concluded, with additional experiments to delineate the effects of age on hearing. A paper describing the investigation was published in the May 1956 issue of the *British Journal of Applied Physics*.

Various novel ultrasonic devices have been under development, e.g. a stable line giving 6 ms delay for $\frac{1}{3}$ μs pulses at 1 Mc/s using torsional waves in steel, and another for 100 μs, using Permendur with extensional waves; a robust viscometer using torsional waves either with a ferrite transducer or with a barium titanate transducer; steerable beam flaw detectors with automatic motor-driven sweep and methods for monitoring the contact between probe and specimen, during flaw detection by ultrasonic equipment.

The Test House work continues to grow. Additional responsibilities recently assumed include tests on thermometers for deep-sea work, gun sights for the Admiralty, red rear reflectors and trichloroethylene inhalers for the Central Midwives Board. The inhalers are tested by interferometric means, since the percentage of trichloroethylene in a
with air may be ascertained from the refractive index
mixture. A modified Jamin interferometer gives a
screen indication of the percentage of trichloroet
delivered by the inhaler.

Courses in horology and instrument technology

The full-time courses provided at the National Coll
Horology and Instrument Technology cover the
manufacture and application of horological mech
(including watches and clocks), and instruments (inc
electronic instruments and automatic control devices)
Diploma course consists of two years' full-time study
college, a "sandwich" course of six months in industr
twelve months at the college, followed by one and a half
continuous training in industry. Those wishing to ta
course should have the General Certificate of Educat
"O" level, or equivalent, in mathematics, physics and E
The Post-graduate course provides an introducti
specialized aspects of instrument design, manufactur
use, etc., for graduates. The duration of this full-time
is nine months (from October to June).

Further details can be obtained from Dr. J. E. Richa
National College of Horology and Instrument Techn
Northampton Polytechnic, St. John Street, London, E.

Journal of Scientific Instrument

Original contributions accepted for publication in future of this Journal

A high temperature micro-thermostat for X-ray studies on single cr appreciable vapour pressure. By P. J. A. McKeown.
An instrument for the measurement of salinity in estuaries. By E. G.
A simple scanning mechanism for X-ray diffraction. By G. W. Smith an Hinde.
A miniature eight-channel pressure recorder. By H. M. Nelson and G. A
The application of pneumatic gauging to high precision linear meas By J. C. Evans and I. G. Morgan.
A fast coincidence system for the measurement of short lifetimes. By and J. B. Warren.
An alinement and co-ordinate system for nuclear emulsion stacks. Silverstein and W. Slater.
A portable instrument for respirable dust sampling. By R. J. Hamilton.
An electrostatic null detector. By J. Hart and A. G. Mungall.
An instrument for the continuous measurement of shrinkage of texti By R. A. E. Ellis, K. W. Hillier and A. B. Thompson.
A Kosters-type interferometer. By C. F. Bruce.

British Journal of Applied Physic

Contents of the September issue

SPECIAL ARTICLE

Crystallography and the phase rule. By A. R. Ubbelohde.

ORIGINAL CONTRIBUTIONS

Preparation of scattering foils of uranium by evaporation of the metal vacuum. By K. K. Damodaran.
The viscosity of mixtures of gases at high temperatures. By M. J. Kenne Sarjant and M. W. Thring.
Focal properties and chromatic and spherical aberrations of the three-e electron lens. By G. D. Archard.
The accuracy of particle size determination by cumulative sedimentation n By J. K. Donoghue.
Uniform-field breakdown in air. By R. F. Saxe.

NOTES AND NEWS

New books
Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the princi construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Squ London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparatio contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applica from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Lon E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received withi days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of add or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payabl advance. Single parts, so far as available, may be purchased at 10*s.* each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institut Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

Fine measurements*

By J. R. ADAMS, B.Sc., A.M.I.Mech.E., Taylor, Taylor and Hobson Ltd., Leicester

The limitations of the existing legal standards of linear measure are considered. The use of light waves as a universal reference of linear measure depends on the availability of a source of truly monochromatic light and considerable progress has been made using the isotope ^{198}Hg. Many aspects of engineering require measurements accurate to a few micro-inches and instruments capable of meeting such demands have been designed. Several typical instruments, together with details of the principles on which they are based, are briefly reviewed.

e purpose of this paper is to review the fundamental basis on which linear measurements are established and then to nsider several instruments used for various forms of fine asurements, discussing some of the principles upon which y are based.

BASIS OF LINEAR MEASURE

n the United Kingdom the legal standard of linear measure he Imperial Standard Yard. The physical standard is in form of a bronze bar 38 in. long and of 1 in. square tion into which are set two gold plugs 0·1 in. in diameter h one face of each plug lying on the neutral axis of the . On each plug is engraved three parallel lines at right gles to the length of the bar and 1 yard is defined as the tance between the central lines of each block when the nperature of the bar is 62° F. Over the years, it has been ablished by periodic comparisons that the length of this ndard has decreased in the order of some two parts in a llion.

The American standard of linear measure is based on the ernational Prototype Metre which is in the form of a tinum bar of a modified H-shape cross-section carrying graved lines on its neutral axis in a similar way to the perial Standard Yard. The American Standard Yard is ived from the Metre, using a conversion factor of 00/3937. The true relationship between the British Imperial rd and the International Prototype Metre is 3600/3937.0147 d the difference between these two conversion factors gives e to the fact that the American inch is 3·7 micro inches 000 003 7 in.) longer than the British inch. The significance this can be appreciated when it is realized that reference s of slip gauges when calibrated at either the National ysical Laboratories or the National Bureau of Standards, specified to the nearest millionth of an inch.

The Canadian Standard Yard is based on the relationship 1 in. being equal to 25·4 millimetres with the result that Canadian inch is 1·7 μin. (0·000 001 7 in.) longer than British equivalent.

Obviously it is most desirable to establish a fundamental sis of linear measurements, and recently work has been ogressing at the National Physical Laboratories towards h an objective.(1)

Another approach is based on optical methods but one ficulty has been to obtain a source of light which has one ndamental frequency. Of recent years, however, an isotope mercury (^{198}Hg) has become available and it has thus been ssible to make lamps capable of emitting truly monoomatic light. With the aid of these lamps it has been possible to take linear measurements up to distances of 18 in. to an order of accuracy of one part in ten millions. This, however, falls short of the required measurement over 36 in. and therefore work continues in an endeavour to establish equal accuracy over a distance of 1 yard and having reached such a stage it will then be possible to give serious consideration to a change in our legal form of linear measure. The principles employed in establishing linear measure by reference to light waves are now extensively used for the absolute measurement of slip gauges, and various types of interferometers have been constructed for this purpose.

The principle of optical interference has been applied to problems other than those of linear measure, for example, the inspection of surface finish. The need of a truly monochromatic source is essential if accurate sub-division of the half wavelength is to be obtained in order to take micro-inch readings. The use of interferometry and its application to engineering problems is becoming increasingly appreciated, and Prof. S. Tolansky(2) has shown that many details such as the structure of metals and other materials may now be readily examined and thereby the life of components, designed to withstand greater working loads, may be more readily assessed.

CLASSIFICATION OF PRINCIPLES

The most universal form of standards of length employed in engineering are gauge blocks and these form the basis of calibration of many engineering inspection instruments. The calibration tolerances of such instruments are often quoted in micro-inches thus making it essential to take into account the errors of the gauge blocks being used. Various principles are employed in these instruments to amplify small increments, the four main groups being: (*a*) mechanical; (*b*) electrical and electronics; (*c*) optical; (*d*) pneumatic. A combination of principles from two or more of these groups may be found in any one instrument.

An example of a purely mechanical instrument is the ordinary micrometer using a screw thread calibrated in thousandths or ten thousandths of an inch. Instruments employing electrical or electronic principles are illustrated by the Talysurf Surface Measuring Instrument, and the Talyrond Roundness Measuring Instrument. Examples of optical instruments include profile projectors, microscopes, autocollimators and alinement telescopes. Pneumatic principles have been employed in various forms of comparators.

ELECTRICAL INSTRUMENTS

For the purposes of this paper the Talyrond Roundness Measuring Instrument is described as an example of instruments which employ electrical principles as a means of amplifying small displacements. The value of this instrument is appreciated best by considering the various ways in which efforts have been made to assess roundness errors. One of the most common methods is to rotate the component in a Vee block with an indicator mounted immediately above the axis of the component. Radial errors will result in a movement of the indicator pointer. The readings so obtained need to have a correction factor applied in order to truly assess the error, as it is known that the angle between the faces of the Vee block will determine the extent to which any error is reproduced. This is illustrated by considering a specimen having ten undulations equally spaced around its periphery which is rotated in Vee blocks of various angles. If the angle is suitably selected (i.e. 72°) a reading equal to approximately twice the radial error is obtained, whereas at other angles (i.e. 36° and 108°) it is possible to eliminate any indication of error. At some suitable angle (i.e. 90°) there will be a position at which a true indication of the radial errors will be obtained.

---

* This paper was read before a meeting of the Midland Branch The Institute of Physics on 13 March, 1956, after a tour of the rks of Taylor, Taylor and Hobson Ltd., in Leicester.

One of the first instruments designed to obtain a graphical record of the radial errors was the Taylor–Hobson Roundness Attachment, which incorporates a Vee block carrying two anvils so constructed that the included angle between them can be adjusted from 45° to 150°. These anvils are also radially adjustable to accommodate specimens varying in diameter from $\frac{1}{4}$ to 4 in. A motor unit provides a rotational drive to the specimen of one revolution per minute. When used with the Talymin Recording Power Unit, a graphical representation of the radial errors is produced on a linear graph. There are, however, serious limitations to this arrangement of which the following are the most obvious:

(*a*) The range of components that can be accommodated is limited.
(*b*) Normally, only external diameters can be checked.
(*c*) Angular orientation of the errors on the component are not easy to correlate with the errors shown on the graph.
(*d*) It becomes practically impossible to obtain a useful reading if the errors are unequally spaced around the circumference.

The Talyrond roundness measuring instrument (Fig. 1) overcomes these difficulties. An electric displacement indicator or pick-up is mounted on the lower end of a prec
spindle. A stylus arm extending from the underside c
pick-up engages the surface of the specimen that is
checked. The specimen is mounted on a work table
remains stationary during the measuring cycle. The a
the specimen is set in line with the axis of the spindle so
when the spindle rotates the stylus tip will be kept in en
ment with the surface of the specimen. Assuming fo
moment that this setting has been made exactly correct
any errors in roundness will result in a radial moveme
the stylus arm. These radial movements differentially ac
two variable air gap inductances and so cause an ou
balance current to be generated in an a.c. bridge.
current is amplified and fed to a polar recorder. R
amplification can be varied from ×50 to ×10 000, so th
large range of errors may be readily recorded. The pic
is radially adjustable to accommodate specimens havi
range of outside diameters from $\frac{1}{16}$ to 14 in. and a rang
bore sizes from $\frac{1}{8}$ to 12 in. The change from interr
external measurements is quickly accomplished by disp
ment of a small lever on the pick-up. The spindle is
carried in a head mounted on a vertical slideway and ma
elevated to accommodate specimens of varying heights.

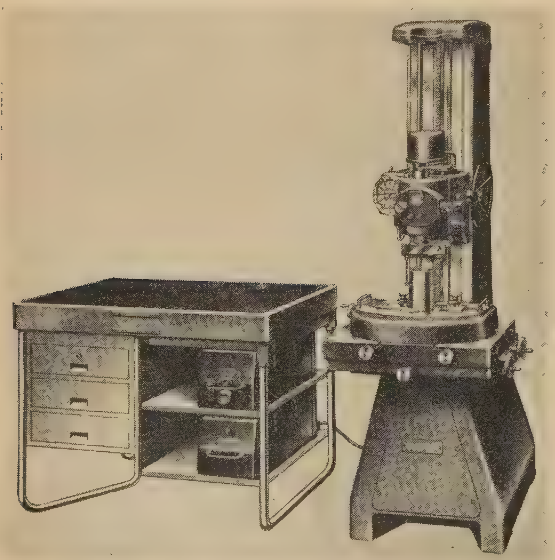


Fig. 1. Roundness measuring instrument (Talyrond Model I)

It is essential that the axis of the component be set
in line with the axis of the spindle, and in order to make
setting a speedy operation a special centring table is prov
on which cylindrical specimens can be rapidly set such
their axes are concentric to the spindle axis within 0·0
Further refinement is obtained by movement of the sp
in the head in two directions mutually at right angles to
other, by means of micrometers mounted in the front c
The centring operation is normally performed with the sp
rotating and observation of the swing of an indicating
mounted in the front cover indicates the degree of refine
to which this operation has been performed. Adjustme
the micrometers is made until the swing is a minimum.
the error of centring is reduced, so the radial amplifica
may be increased until the errors may readily be reco
on the graph. At a magnification of ×50 the maxi
radial error that can be recorded is 0·02 in. and at ×1
the value is 0·0001 in.

One of the problems which is immediately faced in i
preting results obtained on the Talyrond is that of
definition of true roundness.(3) Fig. 2 illustrates three
grammatic components in which (*a*) is round, but (*b*) an
have radial errors whose amplitudes are equal. The t
specimen would be said by many to be out of round, whe
the second specimen would often be classed as being rou
However, the only difference between the two specime
the frequency at which the error occurs around the periph
In the first case the frequency per revolution is 12, whe
in the second case it is 3. Whether such errors will adver
affect the performance of components on which they o
will depend on the function of the component. And so
assessing the value of roundness errors that may be toler
in a given component, an understanding is required of
part to be played by the component and of the conditi
under which it is to work, together with an indication of
errors in any mating components.

Figs. 3 and 4 illustrate typical Talyrond graphs. Fi
illustrates the radial errors found on the bore of a taper ro
race; the race member has seven major undulations on w
are superimposed a large number of minor irregulari
This has been found to be indicative of the process used i
manufacture, i.e. centreless grinding. In order that the m
errors can be readily assessed graphs can be obtained in w

minor irregularities are filtered out. This is also shown Fig. 3. If diametrical measurements are taken on a speci-n having this form of error, such measurements will be nd to be equal wherever they are made. This would not so on a specimen having an even number of undulations.

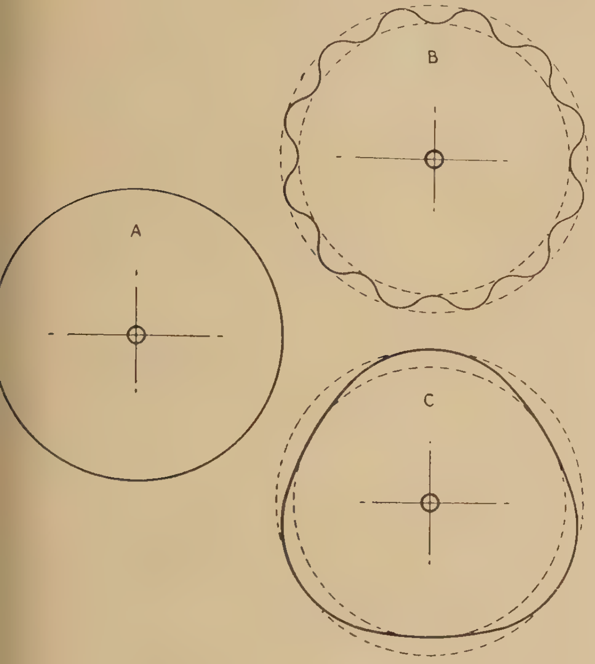


Fig. 2. Types of roundness errors

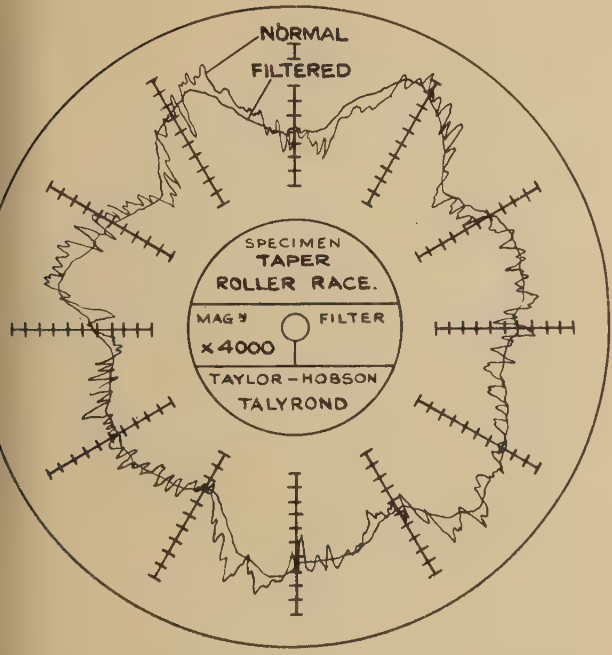


Fig. 3. Talyrond graphs of taper roller race

The datum from which radial errors are measured is pro-ed by the precision spindle to which the pick-up is mounted. is spindle has optically worked bearings and is so con-ucted that the maximum permitted radial error from a true circle does not exceed 3 μin. The spindle error is assessed by reference to an optically polished glass hemisphere. A graph taken on the glass master will, therefore, have a combined error of the spindle and of the master superimposed. If the glass is rotated through 90° in the plane of the work table, and a new graph obtained, any deviation from a true circle that is observed on the graphs as a result of spindle imperfections will remain in the same orientation, whereas errors in the glass will have moved through 90°. In this way the radial errors of any spindle are assessed. One of these test hemispheres is supplied with each instrument so that the user himself may check the performance of his spindle. Radial calibration is verified by reference to two standards in the form of steel cylinders having flats lapped along their length. A trace obtained from one of these cylinders will reveal a circular graph with a single radial kick equal in height to the depth of the flat on the cylinder, multiplied by the amplification of the instrument. A cylinder having a flat of a radial depth of 80 μin. will, therefore, appear on the graph at a magnification of ×10 000 as a trace with a radial kick of 0·80 in.

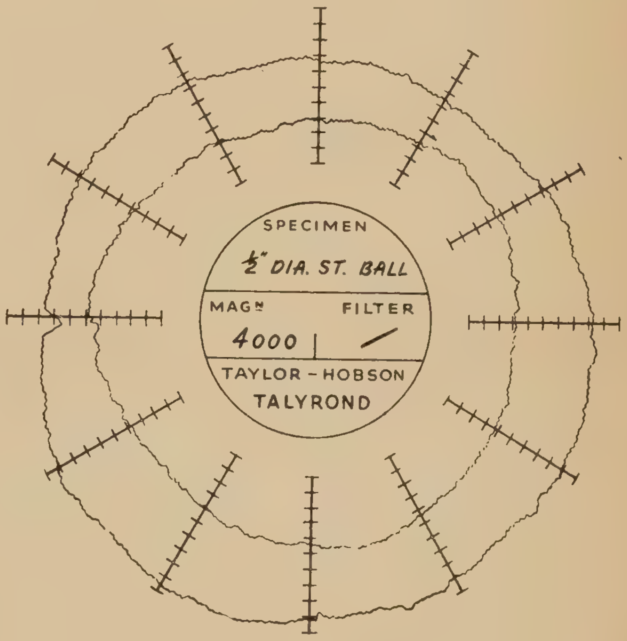


Fig. 4. Talyrond graphs of steel ball

OPTICAL INSTRUMENTS

The application of optics in the engineering industry has rapidly increased during the past twenty-five years and now covers many branches of engineering inspection. One well-known application is found in the profile projector of which there are many types now available. Some projectors are designed for universal adaptation, whereas others are more specialized to suit the requirements of a particular type of component. The basic principles of profile projection are illustrated in Fig. 5. A light source mounted coaxially with a suitably designed condenser lens provides a collimated or parallel beam of light at the work plane. The light is collected by a specially designed and chromatically corrected projection lens and is then projected on to either an opaque or transluscent screen by a system of mirrors. An example of a profile projector is the Taylor–Hobson 200 in. projector. One form covers a 3 in. field and another covers a 6 in. field. Both projectors utilize a horizontal opaque screen 6 ft in diameter and positioned 3 ft from the ground level. Focus controls are adjacent to the viewing screen so that the operator has complete control at his measuring position. A range of lenses provides magnifications from ×10 to ×100.

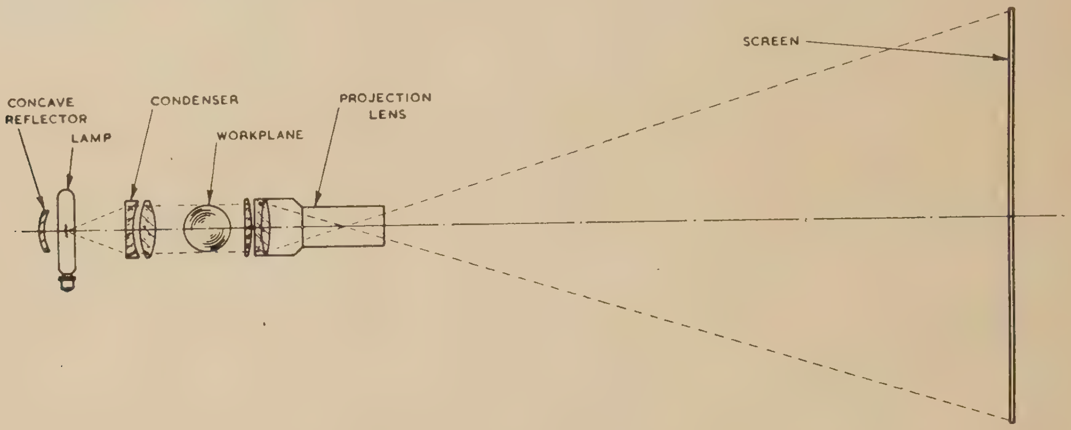


Fig. 5. Optical principles of profile projectors

Fig. 6 emphasizes the need for collimated light in the work plane. If a convergent or divergent beam of light is used the projected image of, for example, a steel ball will represent the size of the ball at the point of tangency *A–A* of the principal rays on the periphery of the ball. This will be seen from the illustration to be less than the true diameter. Only truly collimated light will enable an image of the true diameter *D–D* to be projected.

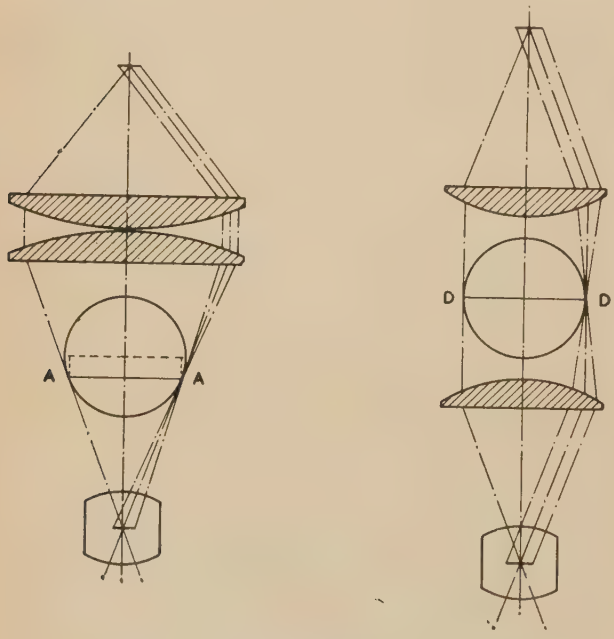


Fig. 6. Illustrating the necessity for collimated light in the work plane

A profile projector designed for the inspection of a specific type of component is illustrated by the Taylor–Hobson blade projector (Fig. 7) used for the inspection of the aerofoil cross-section of turbine and compressor blades. The o principles of this projector are shown in Fig. 8. The l is mounted in line with the axis of a wide-angle proje lens with the particular section to be inspected delin either by projecting a slit of light around the section o marking a white line on the surface of the blade. In latter case the line is then illuminated by a high inte light. This section is then brought into the focal plan the lens and an image is formed on a transluscent scree ×10 magnification. This projected image is compared a master outline marked on the screen. By means of a sp mirror system two sections can be projected on to the s simultaneously. The blade is surrounded at a point mid between the two sections to be inspected by specially sh mirrors enabling one section to be viewed directly by lens and the other section by reflexion in the mirrors these mirrors are correctly adjusted along the blade sections are brought into focus simultaneously. In this the twist between the sections and their position relativ root are readily inspected.

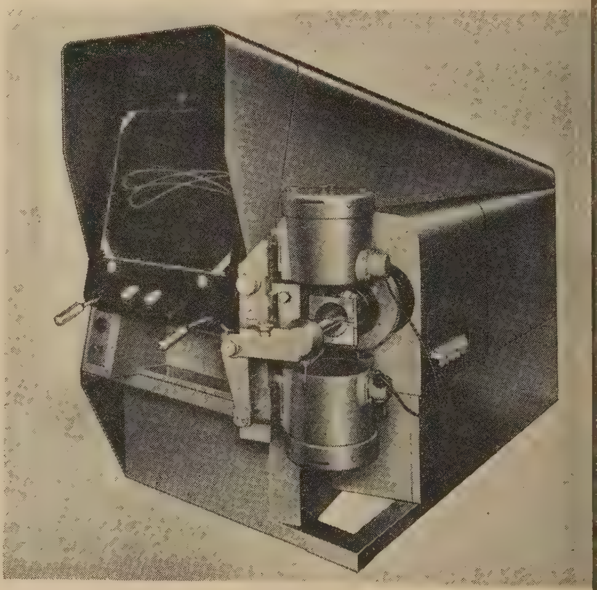


Fig. 7. Blade projector

A further requirement of the aircraft industry is for the
spection of the leading and trailing edges of turbine and
mpressor blades. This led to the development of a blade
ge microscope (Fig. 9), an instrument in which a cross-
ction of any point along either edge is observed and compared at ×40 magnification against a master outline viewed simultaneously in the eyepiece. A narrow band of light is projected obliquely on to the edge of the horizontally mounted blade. This line of light is then viewed obliquely through a microscope so designed that the obliquities cancel out. The blade is spring loaded into a Vee block and is moved axially so that the whole edge may be scanned. By reversal of the blade, sections right up to the shroud may be viewed.

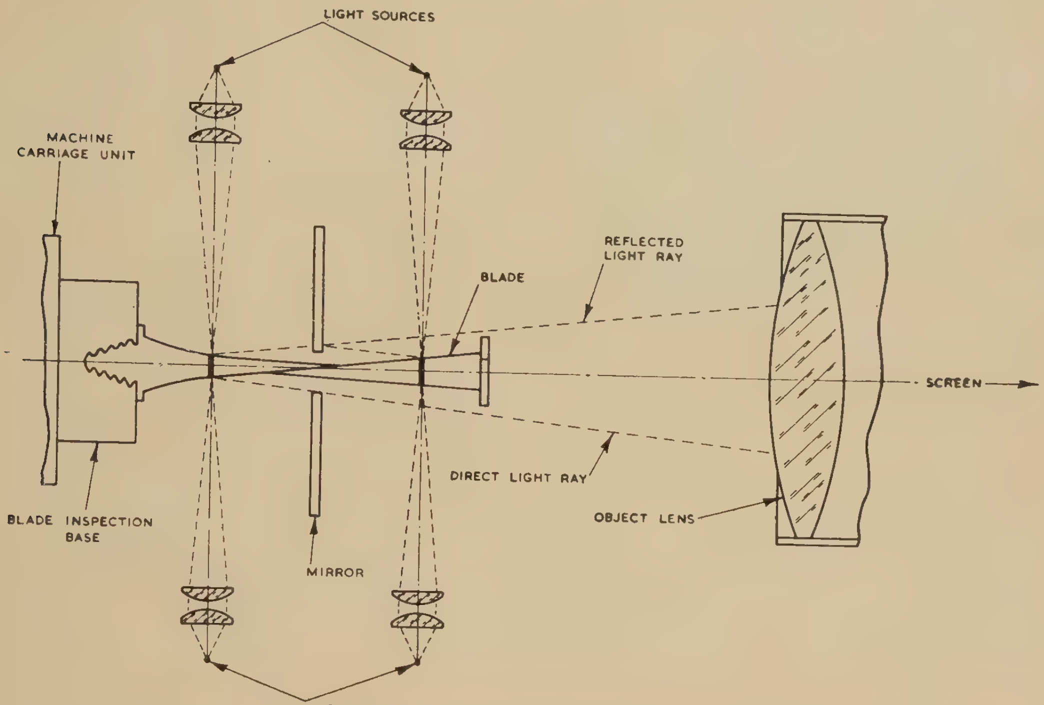


Fig. 8. Optical principles of blade projector

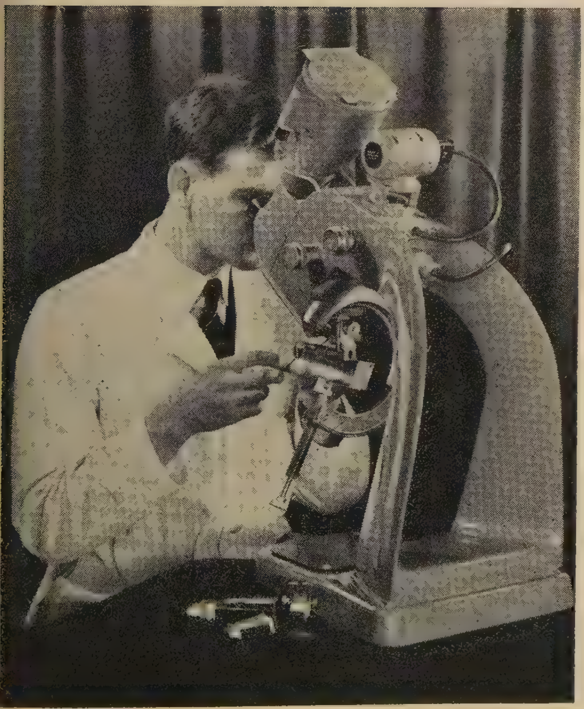


Fig. 9. Blade edge microscope

The blade edge microscope is illustrative of the many forms in which optical microscopes are now being used in the engineering industry. The inspection of thread form, form tools and small gear teeth are examples of other types of components for which special microscopes have been designed.

Another optical instrument now being extensively used is the micro-alinement telescope (Fig. 10). This instrument provides the means of setting two or more points in a straight line and one of its main applications has been found in the aircraft industry in the assembly of wing and fuselage structures. Such aircraft structures are normally assembled in large framework jigs and the application of the micro-alinement telescope to this type of constructional work has been termed "optical tooling."(4)

The telescope is constructed of a hardened and ground steel tube with the optical elements accurately mounted in the bore, the optical axis being concentric and parallel to the outside diameter of the tube within 0·000 25 in. By means of a fixed object lens and movable focusing lens the image of a target is focused in the plane of a graticule consisting of two lines at right angles to each other. The point of intersection of these lines is accurately positioned on the mechanical axis of the telescope. Readings can be repeated to within

±0·002 in. at 100 ft and proportionately for longer or shorter distances.

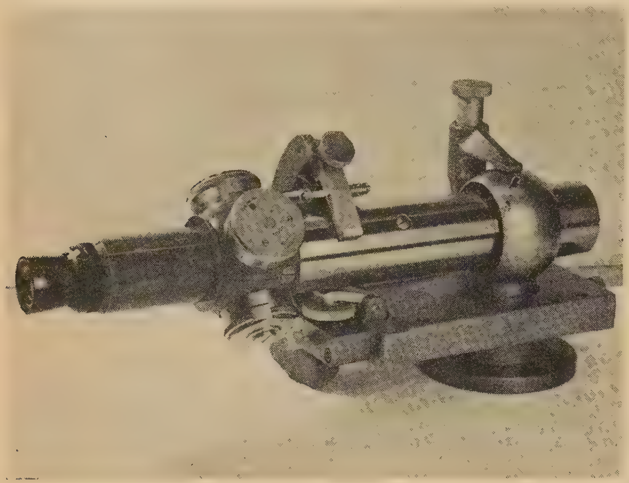


Fig. 10. Micro-alinement telescope in adjustable fixture

Mounted at the forward end of the telescope tube is an optical micrometer comprising a parallel glass block which may be tilted through small angles in any direction. Control of this tilt is by means of two micrometer drums situated just forward of the eyepiece. The effect of tilting this block produces a deviation of the line of sight, this deviation being calibrated in thousandths of an inch on the micrometer drums.

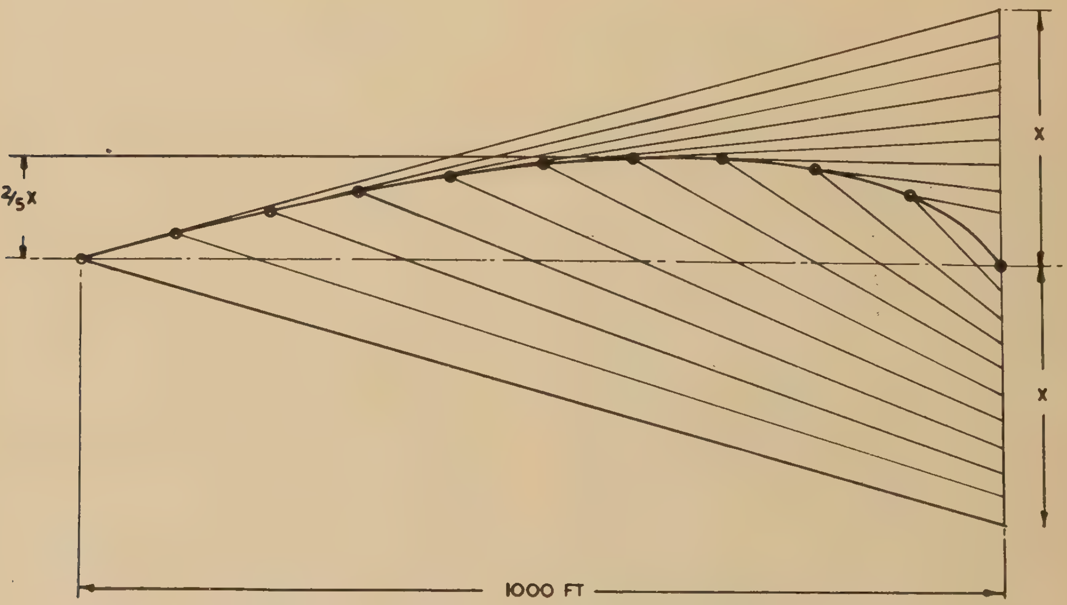


Fig. 11. Probability curve for tube alinement

A series of mounting fixtures has been designed to enable the telescope to be used for different applications. All these fixtures incorporate a mounting sphere to which the telescope tube is attached, the sphere being supported in a cup seating. These spheres are accurately made to locate the telescope tube so that its axis passes through the geometric centre of the sphere. When the initial set up is being made, for exa
on an aircraft framework, it is essential to establish a d
line of sight. With the telescope mounted in a fixture util
a mounting sphere a distant target is viewed, this target
being mounted in a sphere. The telescope is then adjust
its fixture until the line of sight passes through the cent
the two spheres. This is then the datum line of sight.
intermediate target placed in between these two spheres
then be independently viewed by refocusing the telesc
The displacement error of these targets can be measure
readings on the micrometer drums.

One optical accessory which is now being extensively
is the optical square which enables lines of sight t
established in planes truly at right angles to the datum
of sight. The optical square comprises a pentagonal p
which deviates the line of sight through 90° within one se
of arc. This accessory can be attached directly to the sp
in which the telescope is mounted and can therefor
rotated with the telescope when sweeping a complete pl

An auto-reflexion attachment enables squareness mea
ments to be taken. At the forward end of the telescope
a graticule is mounted which is truly concentric to the op
axis. A small lamphouse, attached adjacent to the m
meter drums, provides a source of illumination and
reflected image of this graticule is seen in a mirror place
right angles to the line of sight and appears at a dist
equal to twice the distance between the mirror and the
of the telescope. If the mirror is tilted in any way
reflected image will appear displaced and a measure of
displacement may be used to determine the tilt of the mi
The accuracy of squareness settings becomes greater as
distance between telescope and mirror increases. Sett
can be made to an accuracy of 8 seconds of arc with
mirror 1 ft away from the telescope and to ¼ second
distance of 25 ft and greater.

The application of auto-reflexion is illustrated by
requirement to set the four axles of the carriage wheels

overhead crane truly parallel to each other. A datum of sight was established midway between each pair of ls and in line with the direction of motion. Then using ptical square and with mirrors mounted parallel to each one pair of wheels was set parallel to the datum line of The telescope and target were then interchanged in ounting spheres without introducing any error, and the d pair of axles set parallel to the datum line of sight the same method as for the first pair.

other application illustrates the value of the telescope working over long distances. A series of ten tubes, tube being 100 ft long, had to be set in a straight line. of these sections consisted of a series of other tubes concentric to the main outer tube. These inner tubes first of all, to be set in line and concentric to the outer on. This was achieved by supporting mounting spheres oncrete pillars in between each of the main sections. A m line of sight was then established between each sphere by placing a target in turn at each end of the inner tubes, stments were made to bring their axes truly coincident. as then necessary to set the ten main sections in line; robability of error due to reading the telescope sighted on ecial target 1000 ft away was of the order of ±0·050 in. ing established a datum line of sight between the two distant points, i.e. 1000 ft apart, an intermediate target e end of the first main section was adjusted on to this line ght. The telescope was then moved to this intermediate tion and from there, working at a distance of 900 ft, a line of sight was established, the error of reading being in the order of ±0·045 in. This procedure was then continued throughout each of the ten sections. Fig. 11 illustrates the probability curve of errors in the readings, taken at 100 ft intervals. It will be seen that the maximum deviation from a straight line does not exceed more than 2/5ths of 0·050 in. (0·020 in.).

CONCLUSION

The instruments described in this paper have been selected in order to illustrate both the diversity of the problems encountered in the various branches of engineering today which call for precise measurements and the methods which have been employed to obtain a satisfactory solution.

ACKNOWLEDGEMENTS

The author thanks the Directors of Taylor, Taylor and Hobson Ltd. for their permission to read this paper and for the use of photographs of the company's products.

REFERENCES

(1) Thomson, A. G. *Mechanical World* (October 1952).
(2) Tolansky, S. *An Introduction to Interferometry* (London: Longmans, Green and Co., 1955).
(3) Reason, R. E. *Talyrond Handbook* (Leicester: Taylor, Taylor and Hobson Ltd.).
(4) *Aircraft Production* (August 1955).

ORIGINAL CONTRIBUTIONS

A radioactive ionization gauge and its application to the measureme of latent heat of vaporization

By J. H. Beynon, B.Sc., A.Inst.P., and G. R. Nicholson, M.A., A.Inst.P., Imperial Chemical Industries Ltd., Dyestuffs Division, Blackley, Manchester, 9

[*Paper first received* 13 *April, and in final form* 11 *June*, 1956]

A radioactive ionization gauge useful in the range of pressures 10^{-5} to 10 mm of mercury, and its application to the determination of the latent heat of vaporization or sublimation of organic compounds having vapour pressures in the above range up to 200° C, are described. The instrument uses a 0·5 mc sealed radium source for ionization of the vapour and an electrometer amplifier for measuring the ionization currents produced. Values for the latent heats of fourteen compounds are given.

In thermochemical studies it is often required to measure the latent heat of sublimation or vaporization of relatively involatile organic substances, and this can be accomplished conveniently by making use of the simplified Clausius–Clapeyron relationship, namely:

$$d(\log_e p)/d(1/T) = -L/R \qquad (1)$$

where T is the absolute temperature (°K), R the gas constant (cal/° C mole), L the required latent heat (cal/mole) and p the vapour pressure in arbitrary units. The above simplified equation assumes the vapour to behave as a perfect gas, and neglects the specific volume of the solid or liquid being vaporized compared with that of the resultant vapour. The equation reduces to:

$$L = -4{\cdot}576\, d(\log_{10} p)/d(1/T) \text{ cal/mole} \qquad (2)$$

To determine the latent heat, it is unnecessary to measure the pressure of the vapour absolutely. Provided that any quantity proportional to the vapour pressure (say Kp where K is a constant) is measured, and this quantity plotted on a logarithmic scale against $1/T$, the slope of the graph for any value of T will be independent of K.

Measurement of vapour pressure in the pressure range 10^{-6} to 10^{-2} mm of mercury, i.e. below the useful range of a liquid manometer, requires the use of instruments which are fragile and require a good deal of experimental skill on the part of the operator. Three such instruments have been used in this laboratory. They are the effusion manometer as described by Balson,(1) measurement of the rate of loss of vapour through an orifice by continuous weighing,(2) and a diaphragm-type micromanometer making use of the change of capacitance between a flexible diaphragm and two stationary reference electrodes.(3) Another instrument which could be used for measurement of pressures greater than about 10^{-7} mm of mercury is the well-known ionization gauge, but this suffers from the defects that it contains an incandescent filament which may cause serious decomposition of the sample, and it cannot be used above about 10^{-4} mm of mercury for oxygen-containing substances because of the danger of burning out the filament.

The instrument described in this paper, which overcomes the difficulties in the use of the above instruments, works on a similar principle to the ionization gauge in that charged particles are used to ionize the gas, but the bombarding particles are α-particles from a radium source, instead of electrons from a hot filament. An ionization gauge of this type covering the range 10^{-3} to 10 mm of mercury for air is manufactured by British American Research Ltd., Lanarkshire, under the name Alphatron gauge.(4)

THEORETICAL

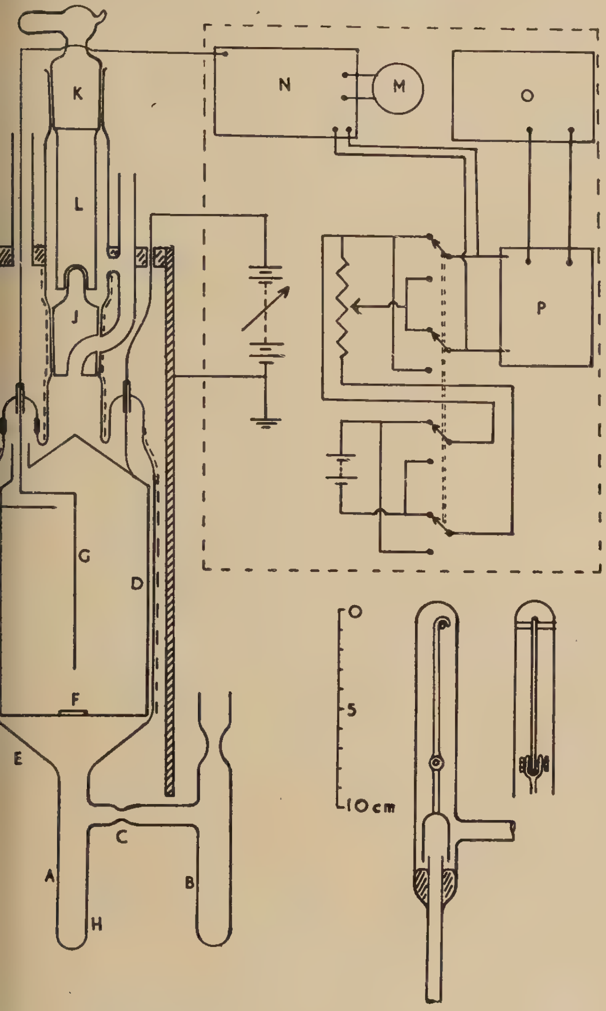
The ionization produced by an α-particle in passing thro a gas depends both on the nature of the gas and on velocity of the α-particle. In general, for a given gas, ionization per centimetre path length of an α-particl directly proportional to the gas pressure and independen the energy of the particle, provided that when the α-par strikes the wall of the containing vessel, it still has an en sufficient to penetrate a further thickness equivalent 0·5 mg/cm². Thus, if the gauge is made too large, line of pressure against ionization current will be lost at the hi pressures.

The approximate sensitivity to be expected from suc gauge has been given by Downing and Mellen,(4) estimated that a radium source of 0·2 mc sealed in sufficie thin foil (so as to retain the radon produced as one of decay products, but still allow many of the α-particle escape) would produce about 3×10^{-10} A ionization cur per millimetre of mercury pressure (in air) when the m path length of the α-particles in the surrounding ioniza chamber was just over 5 cm. The thickness of their foil such that they estimated the effective source activity as of the α-particle activity of unshielded radium. Sim radium sources are sold by the Radiochemical Cen Amersham. For example, 0·5 mc of radium 226 seale a 1 × ½ in. "sandwich" of silver foil from which 30% of α-particles can escape can be obtained.

Shielding of such a source presents no difficulty. Mo electrometers will detect ionization currents as low as 10^{-} so that an ultimate sensitivity of about 10^{-6} mm of mer should be attainable for air. The probability of ionizatio large organic molecules is many times that of air, so for such vapours it might be expected that the ulti sensitivity would be even greater. An advantage of usi radium source in equilibrium with its decay products source of α-particles is that after about a month, the num of α-particles emitted by a sealed radium source change a negligible rate. Radium and its decay products also β- and γ-rays, but the specific ionization produced by t is small compared with that of the α-particles, and car neglected in considering the sensitivity.

TEST OF THE COMMERCIAL EQUIPMENT

In order to test the method for the measurement of la heats of vaporization or sublimation, the commer Alphatron gauge was used. This suffered from the advantage that the housing of the electrometer valve bolted directly to the ionization chamber. For this rea the ionization chamber could not be heated above ro perature, and, since the temperature of the ionization mber had to be greater than that of the sample of which vapour pressure was being measured so as to prevent densation, pressure measurements could only be carried on substances having vapour pressures of more than ^{3} mm of mercury at temperatures below 20° C. The hod of introducing samples was similar to that used with designed gauge-head (Fig. 1) for more involatile samples, asurement of whose pressure is described later.



ig. 1. Radioactive ionization gauge and associated circuit

/, meter; *N*, electrometer; *O*, d.c. potentiometer; *P*, voltage ratio box.
(For other letters, see text.)

glass sample system consisting of two vertical tubes *A* *B* connected together by a constricted tube *C* was attached he Alphatron by a copper/glass Housekeeper seal, the per being soldered directly to the gauge-head. A pure ple of the substance to be examined was inserted in tube and the apparatus connected to a high vacuum pump. sample was cooled with liquid nitrogen and the system cuated for several hours. The liquid nitrogen was then oved and about half the sample allowed to boil away. s removed dissolved air. The vacuum tap was then closed, *A* immersed in liquid nitrogen, and some sample consed into tube *A*. Tube *B* was then removed by sealing t constriction *C*. Measurements of ionization current at several sample temperatures could then be made by immersing tube *A* in a stirred bath of liquid maintained at the appropriate temperatures, care being taken that the sample temperature never rose above that of the gauge-head, i.e. room temperature. The value obtained for the latent heat of sublimation of solid benzene was 11·2 kcal/mole at a mean temperature of −59·6° C. There appears to be no reliable literature value at such a low temperature, but this result may be compared with the value 11·5 kcal/mole obtained by extrapolating the Antoine equation for solid benzene(5) down to the above temperature. It was, therefore, decided to construct a gauge-head capable of operation at elevated temperatures.

CONSTRUCTION OF GAUGE-HEAD

The gauge-head is shown in Fig. 1. It consisted of a nickel cylinder *D* (the anode) which was a sliding fit in the Pyrex glass envelope *E*. Across the open bottom of the cylinder was fixed a brass strap, and soldered to this was the hermetically sealed 0·5 mc radium source *F*. The nickel cylinder was closed at its upper end by a nickel hood, which prevented α- and β-particles from striking the glass walls. A nickel wire *G* (the collector electrode) was brought out of the glass envelope in the following way. An earthed Nilo-K guard-ring (by Henry Wiggin and Co. Ltd.) was graded on to the Pyrex glass of the envelope, the reason for which is explained later, and a Nilo-K tube, into which the electrode *G* was soldered, was sealed into GS3 glass (by Chance Bros. Ltd.) above this guard-ring. A connexion from the anode was brought out in the same way except that in this case the guard-ring was not present. The anode was maintained at a potential of about 100 V positive with respect to earth by a high-tension battery. The glass envelope was wrapped over most of its surface with metal foil to which were attached several calibrated iron/constantan thermocouples (not shown in Fig. 1). It was further surrounded by a brass former wound with a heater and fitted with a lid. With this system, the whole of the effective volume of the gauge-head could be kept at any desired temperature. Glass tubes *A* containing the samples were sealed on underneath the gauge and a thermocouple was attached to this tube at *H*. Sample insertion was carried out in a manner similar to that already described, except that the less volatile samples had to be driven into tube *A* by gentle heating of the subsidiary sample tube. A graphite-lubricated conical tap *J* was operated by the conventional greased tap *K* through the glass coupling *L*. Tap *J* was used for evacuating the gauge, and when it was closed, the leak along its grinding was negligible compared with the rate of evaporation of the sample. Another type of high temperature tap used in later measurements is illustrated in the insert to Fig. 1. This tap was sealed with liquid gallium, and when closed, by lowering the movable portion into the gallium by means of a magnet, could withstand a pressure differential of several millimetres of mercury.

The apparatus was finally covered with lead sheet to protect the operator from the radiation. At the working position, the dose rate as measured on N.P.L. film badges was less than 0·02 r per working week of forty hours. A rotary oil pump and mercury diffusion pump were used for evacuating the gauge, and as a precaution against possible leakage of radon, the exhaust of the backing pump was fed through a rubber tube to the open air.

EXPERIMENTAL

The standard method of measurement was as follows. The sample to be examined was sealed in position as described above, and immersed in a stirred oil-bath, at a temperature at which its vapour pressure was negligible (less than 10^{-7} mm). With the apparatus evacuated by means of a diffusion pump, the main heater of the gauge-head was adjusted so that the temperature of the latter was at least 20° C higher than the highest sample temperature to be used. The gauge-head temperature was controlled automatically to within $\pm 0 \cdot 25^\circ$ C of the desired temperature by a conventional thermocouple-galvanometer photoelectric controller. The lead from the collector electrode *G* was connected to an electrometer unit through a short length of screened cable so as to measure the ionization currents produced. Tap *J* was closed, and the ionization current measured. This gave the zero correction to be applied. The oil-bath temperature was then raised until a measurable pressure was attained and tap *J* quickly opened and closed. Traces of desorbed air or volatile impurities could be detected by noting whether the pressure quickly returned to the same value. The sample was then allowed to come to equilibrium with its vapour at the prevailing bath temperature (ten minutes was the usual time allowed), and the ionization current and sample temperature were noted. The sample temperature was then raised a few degrees and the procedure repeated. For samples which needed to be examined below room temperature, it was found convenient to replace the oil-bath by a Dewar vessel containing alcohol which had been pre-cooled with solid carbon dioxide. The temperature was adjusted by adding the necessary amount of warmer alcohol.

The electrometer unit used for measurement of the ionization currents was the vibrating reed electrometer, type 1079C (by E. K. Cole Ltd.), and the circuit used is shown schematically in Fig. 1. A variable voltage was fed into the negative feed-back line of the electrometer unit (through the jack connexion normally used for calibration purposes) so as to back-off the reading produced by the input signal. Backing-off the input voltage in this manner has the advantages that the recording meter of the instrument can always be brought back to zero on its most sensitive range (leading to greater accuracy of reading), that voltages greater than the nominal full-scale deflexion of the instrument can be measured (so that the range of measurement is extended), and that the meter need not be calibrated. The backing-off voltage was obtained from a dry battery and precision ten-turn wire-wound helical resistance. A constant fraction of the injected voltage was measured on a precision d.c. potentiometer and the logarithm of this measurement plotted against the appropriate $1/T$ (°K^{-1}). The Ekco electrometer has a zero stability$^{(6)}$ of 10^{-3} V from day to day when using an input resistor of 10^{12} Ω and changes in signal of this amount could be readily detected. The ionization current could, therefore, be measured with a precision of 10^{-15} A, corresponding to a pressure of less than 10^{-6} mm of mercury for most organic vapours. In many cases, of course, the vapour pressure of the substance being measured might be as high as 1 mm of mercury, and it was then usual to reduce the sensitivity of the instrument by carrying out the measurements with an input resistor of, say, 10^{10} Ω.

The effect of varying the anode potential of the gauge is shown in Fig. 2. The gauge is seen to become non-linear at the higher pressures, departure from linearity occurring at a lower pressure the lower the anode voltage. This is thought to be due to the greater chance of recombination of ions the longer their time of transit. At pressures of several millimetres, using the type of tap *J* illustrated in Fig. 1, all curves departed sharply from linearity due, it is thought, not to the range of the α-particles becoming comparable with the gauge dimensions, but to slight lifting of the tap by the sa pressure, with consequent increase of the leak.

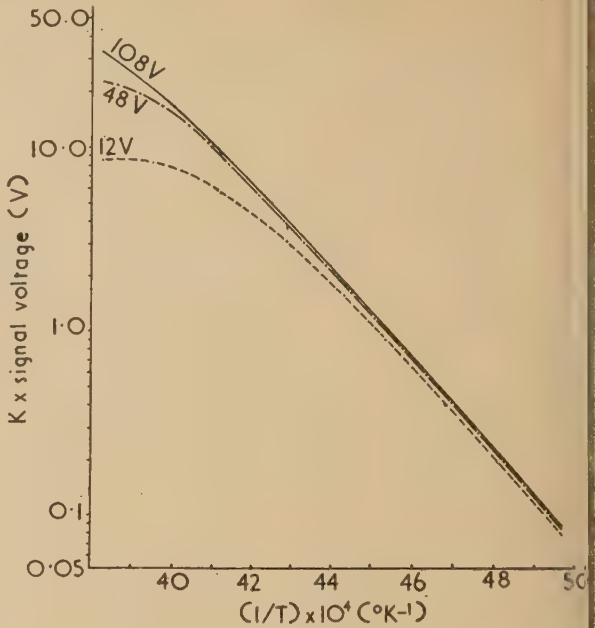


Fig. 2. Effect of variation of anode voltage on linearit of gauge

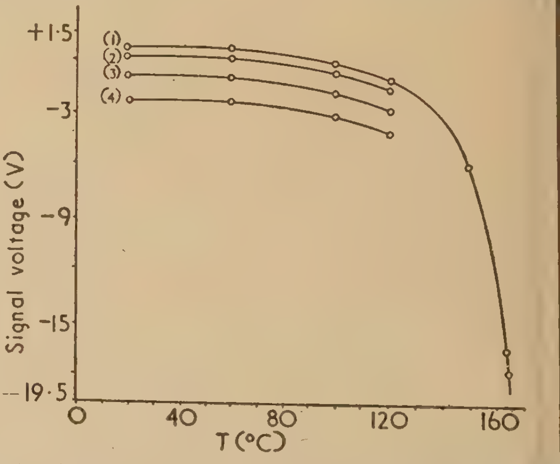


Fig. 3. Variation of zero reading with temperature an anode voltage (without guard-ring at collector electrod seal)

Anode voltages: curve (1), 187 V; curve (2), 145 V; curve (3 83·5 V; curve (4), 42 V.

An effect which led to loss of accuracy at the hi temperatures originated in the glass/metal seals. When equipment was first constructed, both graded seals bringing out the leads were made identical, and simil the anode in Fig. 1. It was found, however, that at h temperatures the collector electrode acquired a considera negative charge. This increased rapidly with tempera above about 120° C (see Fig. 3), the electrode reachin potential of about −20 V at 170° C. This voltage, vary rapidly with temperature, and being larger in value at 170 than even the largest voltage produced by the ion curre rendered the apparatus useless above about 120° C. Fro few measurements made with input resistors of 10^{10} a 10^{12} Ω in the electrometer it appeared that the effect w

The latent heats of vaporization of some solid and liquid compounds

Compound	*State*	*Mean temperature (°C)*	*Vapour pressure ratio*	*L*	*"Estimated uncertainty" in L*	*Estimated L° at 25° C and 1 atm.*	*Mean L°*
				(kcal/mole)			
Benzyl methyl ketone	liquid	27·5	69	13·65	0·05	13·69	13·78 ± 0·06
		27·8	64	13·76	0·03	13·80	
		33·4	22	13·69	0·02	13·80	
		28·6	60	13·76	0·03	13·81	
1, 1-Diphenyl ethane	liquid	44·7	63	16·56	0·06	16·83	16·6 ± 0·4
		40·3	26	16·23	0·04	16·44	
1, 1, 2, 2-Tetraphenyl ethane	solid	158·8	147	30·46	0·05	32·28	32·1 ± 0·4
		163·9	64	30·03	0·12	31·92	
Tetramethyl glycolide	solid	33·9	3·5	18·82	0·03	18·93	18·8 ± 0·4
		25·9	11	19·17	0·04	19·18	
		25·1	66	18·65	0·08	18·65	
		31·0	14	18·20	0·18	18·27	
Anthraquinone	solid	158·8	27	25·20	0·08	26·33	26·5 ± 0·2
		155·0	14	25·42	0·04	26·50	
		155·7	13	25·60	0·08	26·69	
1-Hydroxy anthraquinone	solid	137·8	216	24·14	0·09	25·10	25·2 ± 0·1
		132·4	130	24·30	0·08	25·20	
1, 4-Dihydroxy anthraquinone	solid	133·2	116	24·81	0·29	25·78	25·7 ± 0·1
		137·4	61	24·66	0·26	25·68	
1, 5-Dihydroxy anthraquinone	solid	192·3	3·0	26·26	0·14	28·06	28·2 ± 1·1
		187·7	5·8	26·60	0·15	28·33	
		163·8	45	25·53	0·08	26·90	
		187·3	5·8	27·87	0·24	29·59	
1, 8-Dihydroxy anthraquinone	solid	132·9	156	25·46	0·08	26·43	26·2 ± 0·2
		132·7	146	25·04	0·08	26·01	
		127·7	333	25·31	0·12	26·22	
1-Methoxy anthraquinone	solid	114·3	52	25·58	0·17	26·33	26·2 ± 0·3
		113·7	9·8	25·64	0·11	26·38	
		108·9	4·6	25·20	0·12	25·89	
2-Methoxy anthraquinone	solid	141·6	44	28·37	0·06	29·44	29·4 ± 0·1
		151·1	9·3	28·21	0·07	29·40	
1-Amino anthraquinone	solid	187·8	65	27·16	0·05	28·77	28·7 ± 0·1
		206·8	4·8	26·65	0·01	28·54	
		174·1	173	27·24	0·04	28·65	
1-N-methylamino anthraquinone	solid	128·2	5·1	27·35	0·10	28·25	28·4 ± 0·7
		137·7	19	27·51	0·15	28·52	
		127·6	5·5	28·29	0·11	29·18	
		137·0	18	26·46	0·16	27·47	
2-N-methylamino anthraquinone	solid	187·3	5·3	27·64	0·34	29·34	29·3 ± 0·1
		190·1	7·0	27·56	0·19	29·30	

being caused by a variable "battery," the voltage of which increased with temperature, and which had an internal resistance of the order $10^{12}\ \Omega$. This parasitic voltage appeared to originate in the graded glass of the glass/metal seal, which seemed to behave as an electrolytic battery. The seal was therefore redesigned, as shown for the collector in Fig. 1, to avoid the use of more than one type of glass between the insulated lead and earth. A normal graded seal was built from the gauge-head to a $\frac{1}{2}$ in. diameter Nilo-K tube which was earthed. Between this guard-ring and the Nilo-K lead-out only one type of glass needed to be used. This was found to prevent the lead-out becoming charged relative to the guard-ring, and eliminated the effect almost entirely. Another way of eliminating the effect was found to be to use a molybdenum/high resistance glass seal, so raising the internal resistance of the "battery" to a very high value, and reducing the voltage appearing at the collector electrode to a negligibly small amount.

DISCUSSION OF PERFORMANCE

In carrying out successive sets of measurements with the same sample over approximately the same temperature range, starting each time at the lower temperature end of the range, it was usually found that the derived value of the latent heat increased gradually over the first two or three runs and then reached a nearly constant value for succeeding runs. This was thought to be due to outgassing of the sample, or of the ionization chamber, or both. Outgassing would increase the observed pressure, but the increase would dwindle to zero as outgassing became complete. This effect was less marked in the case of liquid samples than of solids, suggesting that outgassing of the sample itself was the major cause. The first few sets of measurements on each sample were therefore disregarded.

Another noticeable effect in any particular run was that, whilst most of the observed points, when plotted as the logarithm of the potentiometer reading against the reciprocal of the absolute temperature, lay very nearly on a straight line, one or two points at each end usually did not lie on this straight line. The departure from linearity at the low pressure end was concluded to be due to the error involved in the correction for the "zero reading" which was of comparable magnitude to the small signals observed at low pressures. (The "zero reading" was the signal obtained for effectively zero vapour pressure at a sufficiently low temperature at the beginning of the run.) The departure at the high pressure end was due to a falling off of the signal as saturation was approached for the particular anode voltage used, or to slight lifting of the tap. Points at the extremes of the run which clearly lay off the straight line on which the intermediate points lay were therefore ignored, but, despite this, the intermediate points usually extended over a pressure ratio of 50 to 200 for substances of suitable vapour pressure (see the table). The gradient of the best straight line through the observed points was obtained by the method of least squares.

Readings can also be in error at the lower pressures due to thermal transpiration.(7) This occurs when the mean free path of the vapour becomes comparable with the diameter of the sample tube. The measured pressure in the gauge-head will then be higher than that in the sample tube. Let p and T be the sample vapour pressure and temperature, and p_1 and T_1 the corresponding values in the gauge-head. Then, under conditions where thermal transpiration can occur,

$$p/p_1 = \sqrt{(T/T_1)} \tag{3}$$

or

$$\log_e p_1 = \log_e p + 0{\cdot}5 \log_e T_1 - 0{\cdot}5 \log_e T \tag{4}$$

Therefore

$$d(\log_e p_1)/d(1/T) = [d(\log_e p)/d(1/T)] + 0{\cdot}5T$$

since T_1 is constant. Thus, if $T = 400°$ K, say, $d(\log_e p)/d(1$
will be in error by $0{\cdot}5T$, and L, which is of the or
$-2d(\log_e p)/d(1/T)$, will be in error by about 400 cal/m
Any error in L due to thermal transpiration would, in pract
be very small since only one or two readings, if any, at
low pressure end in any single run would be affected;
error calculated above would apply only if all of the readi
in a run were made at sufficiently low pressures.

Most of the previous experience of this laboratory in
measurement of latent heats of vaporization had been w
a Balson(1) type effusion manometer. Comparison of pl
obtained using the radioactive ionization gauge with th
obtained with the effusion manometer showed that
scatter of points around the fitted straight line was, in gene
noticeably less with the former instrument. In addition,
reproducibility of the latent heat from run to run was certai
better with the radioactive ionization gauge. Moreover.
radioactive ionization gauge has been found to be simpler
use than the effusion manometer which requires considera
skill in manipulation, and two or three runs per day, on
same sample, can be done with the former as against o
one with the latter.

The instrument described was found to be unsuitable
use at temperatures much above 200° C, mainly owing to
use in its construction of metals such as cadmium (co
stituents of hard solder) which begin to have an apprecia
vapour pressure at 200° C.

RESULTS

The latent heats of vaporization L of some of the so
and liquid compounds which have been measured are lis
in the table. The "estimated uncertainty" in each value
L caused by the spread of the individual observed poi
about the fitted straight line is shown; this was obtained fro
the calculated "probable error"(8) in the gradient of the li
and gives a measure of the linearity of the set of points. T
ratio of vapour pressures over which each measureme
extended is also shown. The latent heat was in each ca
corrected from its value at the mean temperature of t
measurement to the standard value $L°$ at 25° C and c
atmosphere pressure by the use of known or estimat
specific heats of the solid or liquid and of the vapour. T
limit of error shown after each value of $L°$ was taken to
twice the standard error of the mean.

REFERENCES

(1) Balson, E. W. *Trans Faraday Soc.*, **43**, p. 54 (1947).
(2) Ubbelohde, A. R. *Trans Faraday Soc.*, **34**, p. 282 (193
(3) Opstelten, J. J., and Warmholz, N. *Appl. Sci. Re*
48, p. 329 (1955).
(4) Downing, J. R., and Mellen, G. *Rev. Sci. Instru*
17, p. 218 (1946); British Patent 619,229.
(5) *Selected Values of Properties of Hydrocarbons*, p. 1
(Washington, D.C.: U.S. National Bureau of Standar
1947).
(6) Thomas, D. G. A., and Finch, H. W. *Electronic Eng*
22, p. 395 (1950).
(7) Dushman, S. *Scientific Foundations of Vacuum Tec*
nique, p. 65 (London: Chapman and Hall Ltd., 194
(8) Margenau, H., and Murphy, G. M. *The Mathemat*
of Physics and Chemistry, p. 502 (New York: D. V
Nostrand Co. Inc., 1948).

An alinement and co-ordinate system for nuclear emulsion stacks

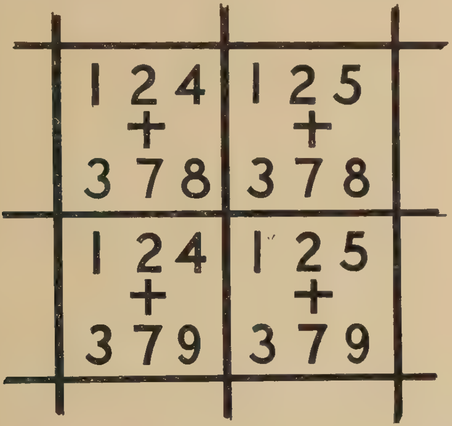
E. SILVERSTEIN, M.S., and W. SLATER, M.S., Enrico Fermi Institute for Nuclear Studies, University of Chicago, Illinois, U.S.A.

[*Paper received* 1 *June*, 1956]

Problems of scanning, trace-through and measurement in nuclear emulsion stacks can be simplified by the use of a co-ordinate system photographed directly on to the face of each pellicle. A method of making and printing a suitable grid that intercepts less than $\frac{1}{2}$% of the useful area, as well as the advantages arising from its use, are described.

nuclear emulsion stacks, the use of a co-ordinate system, "grid," photographed directly on to each emulsion, is y helpful in scanning and also in the trace-through and asurement of particle tracks.

everal groups at the University of California have been ng a grid of this type for over a year.* Their grid consists 6 × 6 in. lattice of perpendicular lines forming 1 × 1 mm ares. Each square has a cross in the centre, and is nbered with a three-digit x-co-ordinate and a three-digit o-ordinate, as shown in Fig. 1. These lines are 35 to μ wide and the numerals are about 270 μ high. This tem covers about 20% of the surface area, but it is usually nted lightly so that the area covered is not completely scured.



ig. 1. The pattern of the co-ordinate grid used at the University of California

he authors have developed a grid which, while containing entially the same information as the Berkeley grid, covers s than $\frac{1}{2}$% of the emulsion surface. It may hence be printed ch more intensely without causing troublesome obscuran. The co-ordinates on this grid consist of letters just 0 μ high, and thus can be read under higher magnification n can the Berkeley grid co-ordinates.

ig. 2 serves to illustrate the principle of the co-ordinate tem used by the authors. A square lattice of dots, spaced 00 μ apart, is labelled, by capital letters (columns) and ver-case letters (rows), i.e. by (iK) in matrix notation. d-points between lattice-points are marked by unlabelled s. In the *actual* grid, useful area is conserved by suppresg the capital letters in every even column and the lowere letters in every odd column, as shown in Fig. 3.

he following technique has proved to be a simple, inexpensive way of making the negative of such a grid. The pattern (Fig. 3) was typed on to large sheets of white paper using an IBM electric typewriter. This machine spaced the dots 0·5 in. apart, with an error less than 0·03 in. in eleven inches. A square about twenty-eight inches on a side (actually, two narrower sheets, taped together) was used to complete the pattern of twenty-five letters and fifty-three dots (each row and column should begin and end with two dots to facilitate cutting and fitting the negatives together).

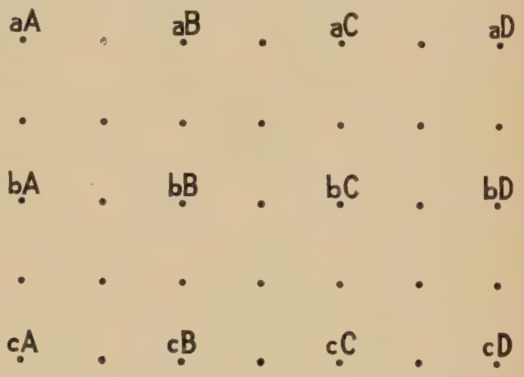


Fig. 2. Example of the matrix notation which forms the basis for the Chicago grid

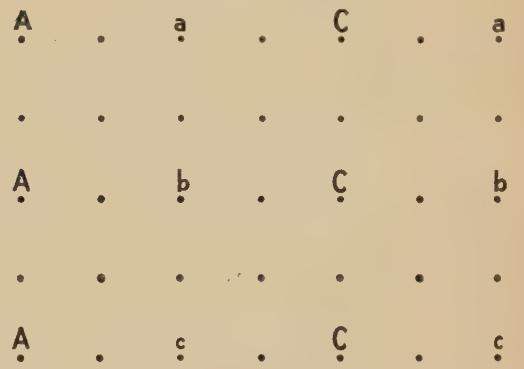


Fig. 3. The actual pattern of the Chicago grid

This typed pattern was then photographed on microfilm, using a reduction of 25·4 times. This can easily be done on conventional library or commercial microfilm equipment. This reduction yielded 1 × 1 in. negatives which printed dots about 30 μ in diameter and letters about 100 μ high with a line width of about 25 μ. The r.m.s. fluctuation in the distance between dots was found to be less than 1%.

These microfilm squares were then trimmed on a good paper cutter (using a ×10 magnifying glass) leaving dots at the beginning of each row and column, and letters (Z or z) at the end of each row and column so that the squares could

---

BIRGE, KERTH, RICHMAN, STORK and WHETSTONE. Radiation oratory Report, UCRL 2690 (University of California, 1954). OLDHABER, GOLDSACK and LANNUTTI. Radiation Laboratory ort, UCRL 2928 (University of California, 1955).

be fitted together into a continuous grid. [The accurate cutting of the negatives requires care and is rather time consuming (about three hours for a 4 × 6 in. grid). The authors have tried to print additional grids by making two successive contact prints of the original one, but have so far been unable to achieve satisfactory resolution and contrast by this method.] These squares were then glued, emulsion side up, to a $\frac{1}{4}$ in. thick cellulose acetate sheet. Methyl-ethyl ketone applied with an eye-dropper under the microfilm served as an excellent quick-setting adhesive.

To aline and print stacks, a device which punched four accurately positioned $\frac{1}{8}$ in. diameter holes into each pellicle was used. Immediately after punching, the pellicle was placed against a $\frac{1}{2}$ in. thick micarta block provided with $\frac{1}{8}$ in. holes having the same spacing as the punch. Stainless steel pins, $\frac{1}{8}$ in. diameter, were put through the emulsion and the block, leaving one end of each pin flush with the top surface of the emulsion (Fig. 4). The emulsion was placed in contact with the grid on the printing assembly illustrated in Fig. 5, the micarta block pushed against three locating points on an L-shaped metal piece, and the whole weighted down with a lead brick (20 lb). A five-second exposure to a "point source" giving an illumination of 17 foot-candles was used (a 6 V, 30 W microscope bulb run at 8·5 V).

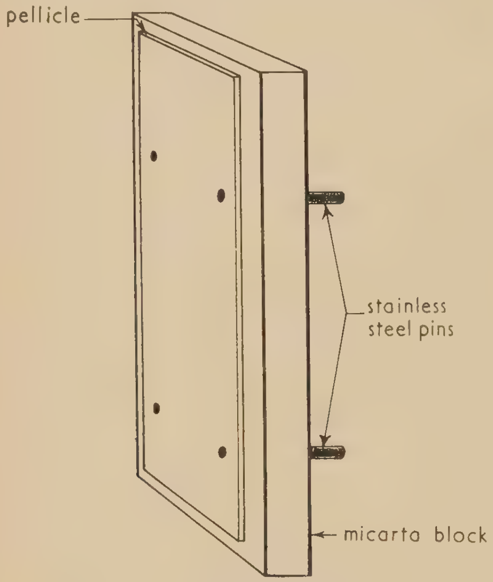


Fig. 4. Method of mounting pellicle on micarta alinement block

Immediately after exposure, the pellicle was removed from the micarta block and stacked on a second identical block with stainless steel pins going through its holes. Subsequent pellicles were stacked over this first one. (No material was used between emulsions.) This method gave an alinement with an average error of about 15 μ.

Since the accumulation of silver on the free surface of the pellicle must be scrubbed off after development, the grid exposure was chosen sufficiently heavy to withstand scrubbing with ethyl alcohol. Methyl alcohol is more effective, but greater care must then be taken so as not to remove the grid completely. Its complete removal may be desirable in case an interesting event is obscured, but since the grid intercepts a very small fraction of the total area, and since it obscures vision to a depth of less than 50 μ at the intercepted area, it is unlikely that one will often find it necessary to remove portions of the grid. Of course, if the grid is printed on bottom of an emulsion which is to be mounted on g

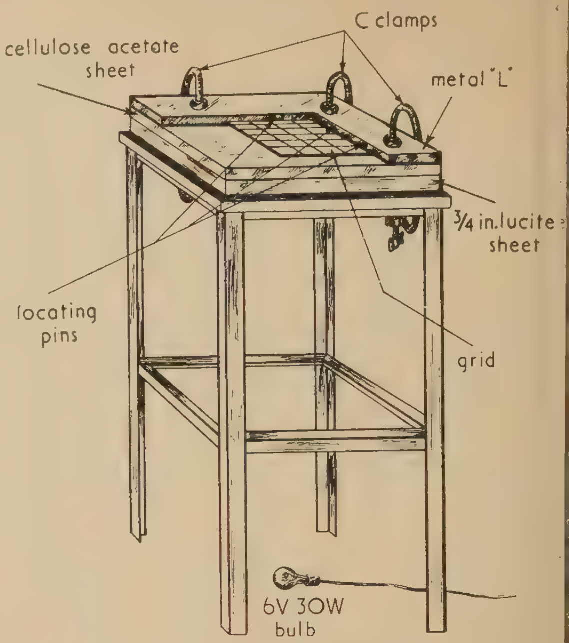


Fig. 5. Grid alinement and printing assembly

before processing, the original exposure should be red since scrubbing, in this case, is neither necessary nor pos

The advantages of a grid used in this way are:

(1) no microscope stage co-ordinates are needed; h microscopes may be interchanged with ease;

(2) area scanning is simplified, since one may, for exa scan along a horizontal strip centred on a given letter and this same letter will appear in each fiel view thus eliminating the necessity of checking c location on the scope co-ordinates;

(3) one can measure ranges of straight tracks by noting grid co-ordinates of the beginning and end of the tr

(4) tracing tracks from one emulsion to the next is gre simplified, since the exact point where a track le one emulsion may be noted on the grid, and the t should enter the next emulsion at the same grid locat

The preceding points apply to all stacks, whether pellicles are processed on or off glass. In particular, the overcomes the disadvantages of processing off glass, and fact, precludes the necessity for mounting, even after pro sing. The most important disadvantage of the free proces method has been that not all of the pellicles attain the s final dimensions, and stacks could not be alined by ventional methods. The grid, as an alinement tool, sc the trace-through problem. It also gives the local la shrinkage factor needed for measuring short ranges. using 1000 μ pellicles rather than the more usual 600 μ c one increases the probability of finding certain conne events (e.g. hyperon decays and stars, and hyperfragme which might go unnoticed if the two connected stars appe in separate plates. These thick emulsions are most easily uniformly processed off glass. Moreover, if the pellicles scanned unmounted, one gains in the following ways: (1) pellicle can be turned over so that events can be obse from both sides under high power. In this way, also, can reach any point in the emulsion with an objective (e.g. Koristka × 100), the working distance of which is less final thickness (0·5 mm) of a 1000 μ pellicle; (2) if an ulsion should be dropped it remains undamaged.

ACKNOWLEDGEMENTS

Ve would like to express our appreciation to Mr. Joseph ch, Dr. Arthur H. Rosenfeld, Mr. David Haskin, Mr. Ray Ammar and Mrs. Elaine Garwin for their assistance in this project. We would also like to thank Prof. V. L. Telegdi and Prof. Marcel Schein for their interest and encouragement.

This research has been supported in part by the Greenewalt Nuclear Physics Fund, the Office of Naval Research and the Atomic Energy Commission.

A miniature eight-channel pressure recorder

By H. M. Nelson, B.Sc., A.M.I.E.E., and G. A. Parker, Aeronautical Research Laboratories, Department of Supply, Melbourne, Australia

[*Paper received* 23 *May*, 1956]

A recorder is described which has been used for pressure plotting in free-flight models at supersonic speeds. The recorder can be fitted with any combination of pressure sensitive units with ranges of 0–10, 0–20 or 0–40 lb/in.^{2} Stylus-on-celluloid recording is used and the total duration of the record is about 40 s. Overall accuracy under normal conditions of use approaches ±1% of full-scale deflexion.

1. INTRODUCTION

seems worth while to describe this instrument, for although has been built for a specialized application and to meet rticularly arduous operating conditions, a recorder of s type may well have applications in other fields. In rticular, the construction of the pressure-sensitive units is more general interest and materially contributes to the w cost and satisfactory performance. For its present plication the instrument must record accurately with plied longitudinal and lateral accelerations of 35 and 5 nes that of gravity respectively, and in ambient temperatures up to 60° C. In addition, the recorder must be able to thstand without permanent damage the high acceleration ak which occurs when the head of the vehicle, which ntains the instrument, is separated from the rest of the ody by a charge at the end of its useful flight.

2. GENERAL DESCRIPTION

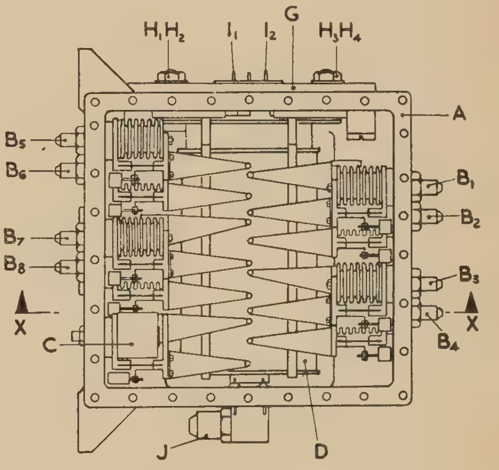
The recorder (Fig. 1) consists of an air-tight cast aluminium-loy case *A* within which are mounted the pressure sensitive its B_1 to B_8, the time marker *C* and the motor driven drum . The lid, *E*, is designed to minimize the chamber volume. e clockwork driving motor *F* is mounted within the rerding drum and the whole motor and drum assembly is tached to the end-cap *G* and can be removed for rewinding d reloading by removing the fixing nuts, H_1 to H_4, rotating e end cap to lift the styli, and withdrawing the whole sembly. Wires connected to terminals I_1 and I_2 can be sed to initiate a datum run of about 2 s duration and later e recording run of 35 s.

The highest pressure to be read is connected to the case rough connexion *J* and the absolute value of this pressure measured by evacuating and sealing one of the pressure its. The loading on all the pressure units is thus inwards comply with the recommendations of bellows manucturers.

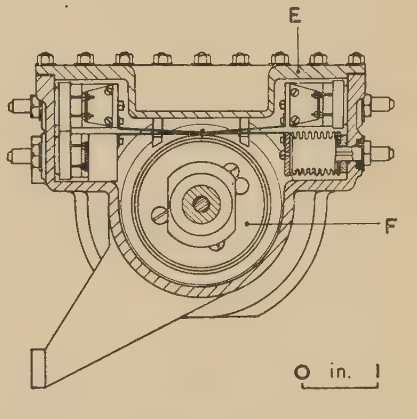
The pressure sensitive units are arranged in a staggered ray, and between each pair of the units a datum stylus is ounted from the case so that wander in the recording um position has almost no effect on the accuracy of cording. The type of record produced is indicated in g. 2.

3. PRESSURE SENSITIVE UNITS

The pressure sensitive units (Fig. 3) consist of a short ngth of metallic bellows *A* soft soldered to brass end caps *B* and *C*. One end cap is sealed, the other has a hollow threaded stem *D* which passes through the case and acts both as fixing stem and pressure connexion. The end caps are attached to dural upper and lower yokes *E* and *F*. Between the yokes a steel spring *G* is fitted and the spring constant of this, or the wall thickness and material of the bellows, can



Plan (lid E removed)



Section X-X

Fig. 1. General arrangement of recorder

be varied to change the pressure range. The upper yoke *E* has attached to it the stylus arm *H* and balancing counterweight *I* the position of which can be varied to obtain freedom from acceleration errors.

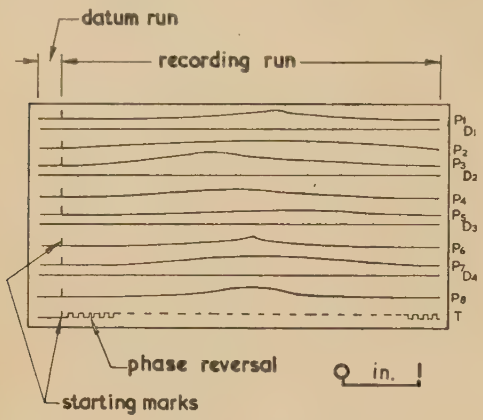


Fig. 2. Typical record

P_1–P_8: pressure traces.
D_1–D_4: datum traces.
T: timing trace.

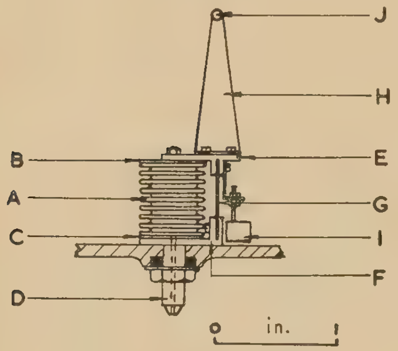


Fig. 3. Pressure unit

The stylus *J* has a tip radius of about 0·001 in. Shortened sapphire-tipped gramophone styli have been mostly used, but hardened steel styli have been shown to work equally well.

A somewhat similar bellows movement has been described previously.* In this movement, however, the backing spring is soldered to the edge of the bellows themselves.

4. ACCURACY

4.1 *Reading accuracy.* The record is read with a coordinate measuring microscope at a magnification of about 25. Transmitted collimated light is used and the general appearance of the trace is shown in Fig. 4. Setting of the cross-wires within the dark bands of the trace can be repea with an accuracy of ±0·005 mm so that with an ove stylus deflexion of 2·5 mm a reading accuracy of ±0·2% full-scale deflexion is achieved.

4.2 *Calibration curve.* Before calibration each press unit is subjected to several hundred pressure cycles fr zero to 120% of full-scale pressure. This procedure resulted in much improved performance.

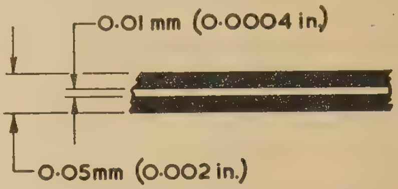


Fig. 4. Appearance of magnified trace

A typical calibration curve for three 40 lb/in.² units shown in Fig. 5. The performance of units of other ran is similar. It will be seen that all units show the same patt of deviation from a linear relationship. It has been fou that, although the mean slope of the pressure-displacem curve varies from one unit to another, the calibration cu can be used for all 40 lb/in.² units with an accuracy ve close to ±0·5% of full-scale deflexion.

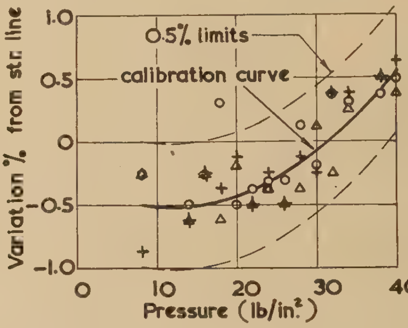


Fig. 5. Typical calibration curve for three pressure channels

△ channel 1
○ channel 2
+ channel 3

4.3 *Temperature effect.* The effect of temperature has be investigated only as an overall effect and no attempt has been made to separate the contributions to temperatu error produced by the various components of the system. number of units were made using bellows of various materi supplied by a number of manufacturers.

The bellows tested were:

Reference	*Bellows material*	*Source of supply*	*Outside diameter* (in.)
A	80/20 brass	Wilcolator (Australia) Ltd.—Australia	9/16
B	aluminium bronze	The British Thermostat Co. Ltd.—U.K.	9/16
C	phosphor bronze	Robertshaw–Fulton Control Co.—U.S.A.	7/16
D	beryllium copper	Robertshaw–Fulton Control Co.—U.S.A.	7/16

Each bellows had a different number of convolutio and a different wall thickness but were chosen to give ve nearly the same range of 0–20 lb/in.² for 2·5 mm styl displacement. Thus the test can only be considered as essment of a particular make of bellows for use in 20 lb/in.^{2} its.

---

* *The Engineers' Digest*, **13**, p. 138 (1952).

The recorder was calibrated at 20, 40 and 60° C. Bellows a given group showed very similar behaviour, so that for sake of clarity the performance of only one unit of each oup has been presented in Fig. 6 in the following way.

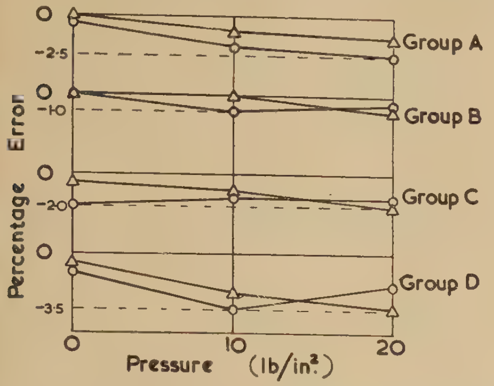


Fig. 6. Deviation from 20° C calibration curve expressed as a percentage of full-scale deflexion for typical pressure units

△ temperature 40° C.
○ temperature 60° C.
Standard temperature 20° C.

e deviations at 40° C and 60° C from the calibration curve tained at 20° C are presented for pressures of 0, 10 and lb/in.^{2} From this diagram it can be seen that units in oups *A*, C and *D* show a shift in zero position with increase temperature accompanied by a change in mean calibration nstant, and the total effect produces an error for units in se groups between 2 and 3·5% of full-scale deflexion. e bellows of Group *B* on the other hand showed a negible shift in zero even at 60° C and the change in calibration nstant resulted in an error of 1% or less at temperature of to 60° C. There was evidence in the units of this group, in Groups *C* and *D*, that the error tended to decrease at higher temperatures and higher applied pressures.

These experiments do not establish the superiority of minium bronze bellows over bellows of the other materials ted, but only the superiority of a particular type of minium bronze bellows when used in this particular embly. The bellows tested were not all geometrically ntical, and furthermore in an arrangement of this type isfactory temperature performance depends on a complex erplay of expansions and variations of elastic constants; that the discovery of a suitable bellows type from so all a sample and without extensive analysis can be regarded extremely fortunate.

.4 *Accuracy of balance.* It has been found practicable to just the balance of the units so that the error at zero applied ssure is comparable with the reading error (±0·2% full- le deflexion) for accelerations of 35 and 5 times that of gravity ng and transverse to the axis of the bellows respectively.

5. RESPONSE TIME

n the present application of the recorder the response lag individual pressure units is more significant than the lag the pressure rise of the case. Tests have been made by ldenly applying pressures to individual units fitted with a ical connecting tube (12 in. of 1/16 in. inside diameter pper pipe) and measuring the time required for the pen to ch the position at which that pressure would be indicated continually applied.

These tests merely give an indication of the response time, for the calculation of response to an arbitrary input function from data obtained from tests of this kind would be extremely difficult for a non-linear system of this type.

The results of measurements made on a typical 40 lb/in.^{2} unit are shown in Fig. 7, from which it can be seen that, after an initial delay which may be composed of either or both transmission delay or switch delay,* the response is similar to that of a second order system of 50 to 100 c/s natural frequency.

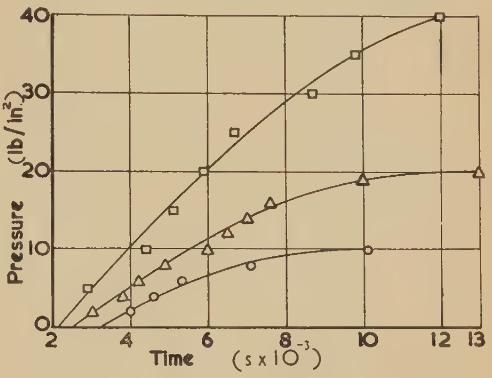


Fig. 7. Response curves for a 40 lb/in.^{2} unit

□ applied pressure 40 lb/in.^{2}.
△ applied pressure 20 lb/in.^{2}.
○ applied pressure 10 lb/in.^{2}.

6. TIME MARKER

The time marking unit is very similar in construction to the pressure units, but the top yoke is made of soft iron and the bellows are replaced by a small cup-type electromagnet. It is also balanced to eliminate movement under acceleration, and is actuated through a relay by a timing watch. A watch was chosen with its balance staff mounted in end-stone type bearings, for this type seems to run more consistently under high acceleration. The hairspring has been shortened and wound in conical form to prevent adhesion of adjacent turns under lateral acceleration and the balance wheel mass has been reduced. Very light platinum contacts have been fitted to the pallet arm and when suitably quenched these contacts control the current of a Siemens high speed relay for several hours without obvious deterioration.

To correlate the internal time marks with the time defined by the test vehicle's trajectory recording instruments, the phase of the timing mark is reversed at the same instant as a mark is made on the trajectory records. This reversal can be clearly seen in the timing record and is indicated in Fig. 2.

CONCLUSION

Several recorders have now been made and used in supersonic free-flight models. Good pressure records have been obtained and the recorders have been recovered by parachute in a condition satisfactory for further service after minor repairs and recalibration.

ACKNOWLEDGEMENTS

This note is published by permission of The Chief Scientist, Department of Supply, Melbourne, Australia. The assistance of V. Dalton in producing early models and in providing ideas during its development is gratefully acknowledged.

---

* The exact cause has not been isolated, but the delay is of the same order as transmission delay in 12 in. of connecting tube.

A high-temperature micro-thermostat for X-ray studies on single crystals of appreciable vapour pressure

By P. J. A. McKeown, Ph.D., Department of Chemical Engineering, Imperial College, London

[*Paper received* 7 *May*, 1956]

A furnace is described to heat slightly volatile specimens up to 1250° C for experiments with an X-ray single-crystal spectrometer. The thermal expansion of alumina at right angles to its hexagonal axis is found to be $L/L_0 = 1 + 6{\cdot}07_4 \times 10^{-6}\,T + 1{\cdot}86 \times 10^{-9}\,T^2$, up to 1230° C.

The advantages of studying thermal transformations of crystals on single-crystal specimens are being increasingly exploited.(1–3) A previously described micro-thermostat(4) for use up to 700° C gives high-precision control of the temperature. However, when it is necessary to examine inorganic salts at still higher temperatures serious difficulties arise with such a design. These are principally due to sublimation of the specimen which coats X-ray windows of the furnace with an absorbent layer, whose stopping power changes with time, often quite rapidly. Also it should be noted that the chemical activity of these specimens requires special care in the choice of furnace materials.

The requirements of a suitable furnace are:

1. It must be suitable for single-crystal operation.
2. The furnace parts and especially the specimen mounting must be unattacked by the specimen.
3. Sublimation of the specimen should be reduced by an air or a gas atmosphere.
4. The X-ray measurements should be unaffected by sublimed material.
5. Automatic temperature control should permit rapid temperature changes without overshoot.

1. Single crystals mounted on fibres to reduce heat conduction almost invariably require to be tilted through a small angle. As a result the end of the fibre away from the specimen seldom coincides with the axis of rotation and so a larger aperture is required than for a powder specimen mounting. Since, however, partial rotation of the crystal is often adequate the hole may be reduced in size if it can be off-set to provide the maximum freedom for a particular specimen. A second factor introduced by the single-crystal nature of the specimen is the comparative unimportance of the absorption and scattering by a gaseous filling and heat reflecting foils in the X-ray beam.

2. To reduce the contamination of, and attack by, salt specimens at high temperature the materials of the furnace and particularly the specimen support must be chosen carefully. With halides, for which this furnace was primarily designed, both alumina and platinum are suitable but only platinum was allowed to come into contact with the specimen.

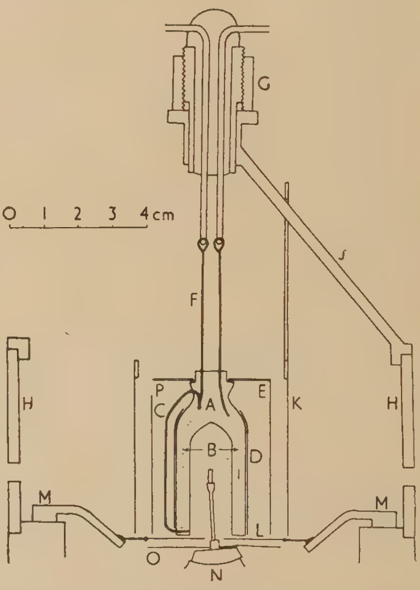
3. A gaseous filling (normally air) is of great importance in reducing the evaporation of some specimens at high temperature. Where oxygen affects the salt,(5) oxygen-free nitrogen may be used. An inert gas of high molecular weight such as krypton would be somewhat more efficient in reducing evaporation, but the advantage is off-set by the much greater X-ray absorption which varies considerably with temperature.

4. When using a closed type of furnace it was found that material sublimed on to foils covering X-ray slots could seriously affect reflexion intensities. It is therefore necessary to keep all such foils and other cool surfaces in the window region free from contamination by means of convection currents. To avoid these introducing excessive temperature gradients, the window should be just large enough for layer line reflexions.

5. To reduce the time required to change the opera temperature the thermal time constant of the furnace m be kept small. This requires a low heat capacity, a high of heat loss and a maximum power input about twice equilibrium value. In order that heat losses should affect the ambient temperature and so cause slow temperat drifts it is necessary to remove waste heat from the furn by means of water or air cooling. In view of the o functions of air convection currents this seems the suitable. Other heat losses to surroundings can best reduced by using wire supports and an adequate system radiation shields. To ensure that the temperature of specimen can never overshoot the desired value, the tempe ture sensitive element must be in the main body of the furn rather than at the specimen.

FURNACE CONSTRUCTION

The furnace and supporting system is shown in the acc panying figure. The main furnace block *A* is made recrystallized alumina cement fired at 1300° C, and the he wire and leads are made of platinum/10% rhodium. X-



Vertical section through micro-thermostat

beams pass through two diametrically opposite slots in each 3·5 mm high and subtending 132° at the crystal positi These slots do not appear in the diagram which is a sect through the furnace in the direction of the pillars joining top and bottom parts of the furnace. The 34 s.w.g. hea wire *B* having thirteen turns above the slots and fifteen alf turns below was welded at the top to 5 cm of 24 s.w.g. re and at the bottom to a similar wire *C* which passed rough the top of *A* for mechanical support. To reduce diation losses a sheet of platinum foil *D* with slots for the rays was wrapped round the furnace but kept from touch- g *C*; and the top of the furnace was carved to provide a pport for a second cylindrical platinum radiation shield *E*. is has slots for the X-rays, a hole at the top for the heater ds and three adjustable slots *P* near the top for temperature adient correction. For specimen temperatures up to about 00° C this shield may be made of aluminium. The leads *F* ing to the top of the alumina block not only carry the ating current but also support the furnace. At the top ey are welded into loops and soft soldered to 14 s.w.g. pper hooks. These are embedded in alumina-waterglass ment in a vertical brass cylinder which may be raised and wered through a distance of 1·5 cm by means of a nut *G*. is assembly is mounted on the collimator holder *H* of the ectrometer(6) by means of three brass rods *J* from which third cylindrical radiation shield *K* of aluminium foil is spended. This foil is not slotted at the window level, ough a small hole permits observation of the specimen.

Heat loss from the bottom of the furnace is reduced by eans of a platinum foil disk *L* held in the centre of a brass ng *M* by means of wires. A central hole 5 mm in diameter lmits a fibre with a small platinum cup for the specimen at e top. The bottom end of the fibre is wedged into a hole a small screw set in the top of the crystal arcs *N*. This rew is also used to hold a lower horizontal radiation shield of aluminium foil.

When using an inert gas atmosphere to reduce chemical tack of the specimen by oxygen, the furnace and its supports ay be enclosed in a vertical brass cylinder, not shown in e figure. This cylinder which is 40 cm high and closed at e top rests on the collimator holder and the slots in the tter are covered with Cellophane. The heater leads are ought through the side of the cylinder which also carries e gas inlet. A slight excess pressure of gas must be used prevent air leaking in as the joins are not all vacuum tight.

HEATING CIRCUIT

The temperature is controlled by making the furnace inding one arm of a d.c. bridge which may be set to balance any desired value of heater resistance. The circuit, which as already been described,(4) required no modification when sed with this furnace.

PERFORMANCE AND TESTS

The performance of the furnace was studied most carefully om 600 to 1000° C, this being the range of temperature equired for present experiments. However, the furnace has een operated satisfactorily at temperatures from just above oom temperature to 1250° C.

In spite of the deliberate encouragement of convection urrents, the thermal efficiency was found to be quite good. power input of 180 W gave a specimen temperature of 235° C. Running for 3 h at this level raised the temperature f the surrounding collimator holder by only 15° C. emperature gradients, however, are somewhat larger and ss predictable than in closed or evacuated furnaces. The ost noticeable feature is the convection heating of the pper half of the furnace. This is mainly corrected by having ore turns of heater wire below the slots than above. Final orrections are achieved by means of the slots *P* which provide convection cooling for the upper half of the furnace. They should never be completely closed or sublimed material may form "stalactites" in the gap in the outer platinum radiation shield.

The vertical temperature gradient which was measured by means of a differential probe thermocouple(4) was found to be almost independent of temperature from 350 to 1000° C and was adjusted to have a value of 1° C/mm (top hotter than bottom) for use with specimens near their melting points. The radial temperature gradient was similarly found to be less than 1° C/mm up to 1000° C.

Before the final temperature calibration was carried out the temperature stability of the furnace was investigated, using a platinum/10% rhodium thermocouple having coiled leads. Two types of temperature change were noted, slow drifts and rapid fluctuations. The furnace temperature was found to decrease slowly, the rate of change being an exponential function of the temperature (5° C/h at 1250° C falling to 0·02° C/h at 700° C). This appeared to be due to a permanent change in the heater windings and not to heating of the spectrometer or changes in mains voltage. Fluctuations of period about 20 s were superimposed on this steady drift and appeared to be due to changes in mains voltage. They increased from about ±0·04° C at 700° C to ±0·16° C at 1000° C and were reduced to about half these values by operating the controlling circuit from a constant voltage transformer.

Since the furnace has no permanent thermocouple, specimen temperatures are obtained from the setting of the decade box of the controlling circuit. This calibration curve was obtained by measuring the Bragg angle of a reflexion from a crystal of known expansion at different settings of the decade box. Since it was desirable that this crystal should be similar in reflectivity to subsequent specimens, a metal could not be used. Single crystals of alumina were chosen both for permanence and for the persistance of high-order reflexions at high temperature. It may be noted that these crystals, which had no optical faces, could be set most conveniently by detecting the required back reflexion on a zinc sulphide screen having an aluminium mirror backing. A crystal with a 36 s.w.g. platinum/13% rhodium thermocouple attached was mounted in the specimen position, care being taken to reduce heat conduction loss as much as possible by coiling the leads. The spacing of the $(33\bar{6}0)$ plane was measured up to 1230° C giving the equation $L/L_0 = 1 + 6{\cdot}07_4 \times 10^{-6}\,T + 1{\cdot}86 \times 10^{-9}\,T^2$ where units of T are °C. The length of the *a* axis of alumina at 25° C was incidentally found to be $4{\cdot}7588_6 \pm 0{\cdot}000\,05$ Å (corrected for refraction). A second alumina crystal was then mounted in a platinum cup on a quartz fibre in the same way as subsequent specimens, and the $(33\bar{6}0)$ spacing measured at noted settings of the decade box. Temperatures derived from these spacings were used to give the ohms-temperature calibration. Specimen temperatures can be obtained by this method to ±2°. However, temperatures in the neighbourhood of a known transition can be determined by means of trial runs to ±0·3 at 1000° C and ±0·05 at 700° C.

Because of the low heat capacity and high rate of convection cooling, the speed of response of the furnace to changes in decade box setting was found to be about 200° C/min. Above 600° C the specimen temperature was found to be within 1° C of the new equilibrium value 4 min after the start of a large temperature change. Even this delay could be considerably reduced by deliberately overshooting the required furnace temperature by a predetermined amount.

ACKNOWLEDGEMENTS

I am most grateful to Prof. A. R. Ubbelohde for his advice and constant encouragement, and to Salford Electrical Instruments Limited for a gift of single crystals of alumina.

REFERENCES

(1) Menary, J. W., Ubbelohde, A. R., and Woodward, I. *Proc. Roy. Soc. A*, **208**, p. 158 (1951).

(2) Kennedy, S. W., Ubbelohde, A. R., and Woodward *Proc. Roy. Soc. A*, **219**, p. 303 (1953).

(3) Gallagher, K., and Ubbelohde, A. R. *Acta Cryst* p. 561 (1955).

(4) McKeown, P. J. A. *J. Sci. Instrum.*, **31**, p. 271 (19

(5) Harpur, W. W., and Ubbelohde, A. R. *Proc. R Soc. A*, **232**, p. 310 (1955).

(6) McKeown, P. J. A., and Ubbelohde, A. R. *J. S Instrum.*, **31**, p. 321 (1954).

The application of pneumatic gauging to high precision linear measurement

By J. C. Evans, B.Sc., Ph.D., and I. G. Morgan, M.A., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 24 *May*, 1956]

The paper describes the application of pneumatic gauging to the precise measurement of the variation in thickness, in each of the three principal directions, of a nearly perfect cube recently used at the National Physical Laboratory in a new determination of the density of mercury by the principle of Archimedes. After discussing the theoretical basis of the method, the experimental arrangements are described and illustrated. It was established that the variations in thickness could be determined with an accuracy of $\pm 1 \times 10^{-6}$ in. ($\pm 0{\cdot}025\ \mu$). Since one of the chief objects of the paper is to draw attention to some of the advantages of the pneumatic gauging technique for linear measurement, mention is made of other uses of the technique at the Laboratory which demonstrate its comparative simplicity and wide flexibility.

The use of pneumatic gauging for the measurement of small displacements or small differences in length offers a number of advantages: the technique is by no means difficult, the flexibility of the method allows wide application and, when desired, an accuracy of $\pm 1 \times 10^{-6}$ in. ($\pm 0{\cdot}025\ \mu$) can be attained with relatively simple apparatus. It is thought, therefore, that an account of its use in some precision measurements recently completed at the National Physical Laboratory might be of interest to other workers. Though the application which will be described is to a particular problem, modification of the experimental equipment to suit other needs presents no difficulty.

In the measurements to be discussed, pneumatic gauging was used to determine the variation in thickness, in each of the three principal directions, of a nearly perfect cube recently used at the Laboratory in a new determination of the density of mercury by the Archimedes principle.(1) The cube is an accurately machined and lapped block of tungsten carbide sintered with cobalt, having sides $3\frac{1}{2}$ in. (9 cm) long and a density of about $13{\cdot}9$ g/cm^3. Its volume was determined, with a standard deviation of about two parts in ten million, from optical interference measurements of the lengths of the edges and the contours of the faces relative to the corners. The results of these measurements could be expressed as variations of the separation of opposite faces. The pneumatic method, by enabling the variations in thickness to be measured directly, offered an alternative to the measurement of the contours of the faces, but to be of value it had to provide the means for comparing these thicknesses to an accuracy of at least $\pm 1 \times 10^{-6}$ in. ($\pm 0{\cdot}025\ \mu$). In the event, the results obtained from the pneumatic measurements, when combined with the interferometric measurements of the lengths of the edges, gave for the volume of the cube a value which agreed to rather better than one part in a million with the value established through the contour measurements.

THEORETICAL CONSIDERATIONS

The simple principle on which the pneumatic gaugi technique is based is illustrated in the upper part of Fig. . Air at constant pressure is supplied first to an orifice O_c a thence to an orifice O_m through which it escapes to t atmosphere; P represents the constant pressure upstream the first orifice and p the pressure between the two orific

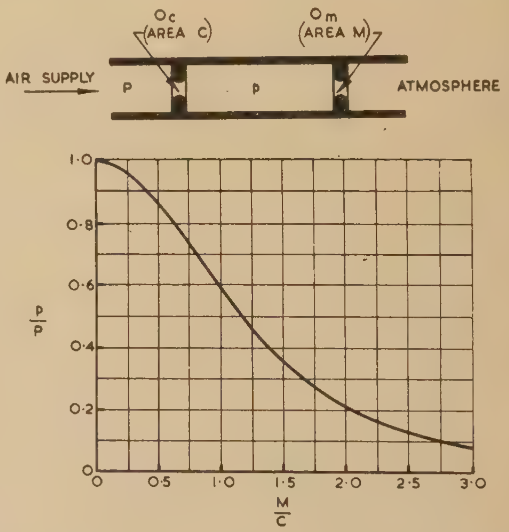


Fig. 1. Principle of method and characteristic curve

both being referred to atmospheric pressure as datum. C and M are the effective escapement areas of O_c and O respectively, the relationship between p/P and M/C is give by a characteristic curve of the general form shown in th lower part of Fig. 1. For values of p/P between $0{\cdot}6$ and $0{\cdot}$

e curve is linear to within 1 % and for P in the neighbourhood 5 lb/in.^{2} (0·35 kg/cm^2) may be represented by the equation

$$p/P = 1{\cdot}1 - 0{\cdot}5\,(M/C)$$

whilst O_c is kept unchanged, so that both P and C are nstant, M is made linearly dependent on a dimensional antity h, then, within the range stipulated, the pressure p ll provide a proportional measure of h. For example, O_m ay take the form of a simple jet with a circular orifice aced normal to a surface which impedes the flow of air om the jet. If d is the diameter of the jet and h the distance tween jet and surface, the effective escapement area M at e jet can be written as $k\pi dh$ where k is a numerical coeffi-ent. Area M is thus linearly related to h and, under the nditions stated above, so is p.

The pneumatic sensitivity dp/dh depends on P and h; the erall magnification depends also on the means used for easuring p. Various instruments are available, such as uid manometers, Bourdon or bellows type pressure gauges d differential pressure gauges; the latter, in view of the nitation on the operating range mentioned earlier, can be ed to particular advantage. When it is required to obtain continuous record of measurement, p may be amplified by eumatic means to a power level suitable for operating cording instruments.(2) In the work on the cube, p was easured by an instrument fitted with a differential diaphragm e Dialair gauge made by the Sigma Instrument Co. Ltd., tchworth), the displacements of which are magnified echanically and read by pointer and scale. The overall agnification was about 22 000.

Small displacements of a surface may be measured by eans of a single jet, as suggested above. Alternatively, en it is required, using the null principle, to keep the ative separation of surface and jet constant the pneumatic uge may be used fiducially. For measuring variation in ickness, two jets connected in parallel may be used in a liper; the effective escapement is then the sum of the capements at the two jets and is thus dependent upon the ickness of the object between them, provided the separation the jets is invariable. Proportionality between p and ckness can be obtained under much the same conditions for the single jet measuring a displacement. The arrangeent is, however, subject to error arising from possible riations in the disposition between the jets of the object ing measured. To achieve the utmost precision it is cessary to eliminate this source of error and this may be ne by maintaining one of the two jets at a constant distance om the corresponding surface. For this purpose a third , mounted on the caliper but in a separate pneumatic cuit, may be used fiducially as mentioned above or, alter-tively, by appropriate modification of the measuring cuit one of the caliper jets may itself be similarly utilized.

The latter method was preferred for the measurement of cube and a schematic of the arrangement adopted is own in Fig. 2. Air at a closely controlled pressure passes ough the control orifice (O_c in Fig. 1) beyond which the cuit divides into two parallel paths connected to the iper jets A and B (which together comprise O_m in Fig. 1). essure tappings upstream and downstream of the control fice are connected to the indicating unit which thus asures $P - p$. To provide for the fiducial adjustment of B, a two-way tap is inserted in the path to jet A. With s tap in the first position (1), the air passes directly to A; with the tap in the alternative position (2), jet A is lated from the circuit and the air passes to an auxiliary ed valve which, as described later, is set during the initial adjustment of the pneumatic circuit to give an air flow approximately equal to that through jet A.

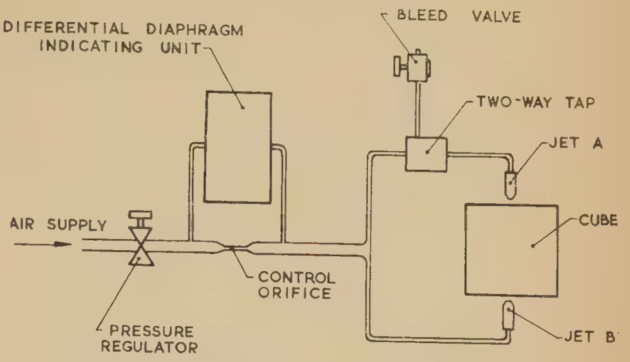


Fig. 2. Schematic of pneumatic circuit used

EXPERIMENTAL ARRANGEMENT

The experimental arrangement used is shown in Fig. 3. The cube was mounted on a circular table which could be rotated about a vertical axis, raised or lowered, and also moved laterally. The caliper, which was made of invar, was carried by a kinematic slide so that it could be traversed in a horizontal direction through a total span of about 4 in. (10 cm) with only very slight up-and-down or sideways play. The two jets were connected into the pneumatic circuit by means of cycle valve tubing which was sufficiently flexible not to exert any appreciable constraint on the caliper as it was traversed. The apparatus was set up in a temperature controlled room and thermocouples appropriately disposed on the faces of the cube were used to detect any undesirable temperature gradients. As would be expected, it was of the utmost importance to establish very good temperature conditions and this was aided by lagging the cube (Fig. 3 shows part of the lagging only, some having been removed to obtain a clearer illustration).

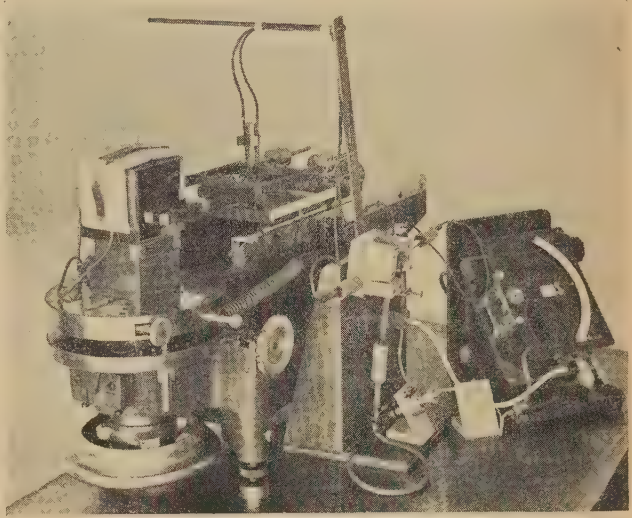


Fig. 3. Experimental arrangements

For adjusting the pneumatic circuit to the required sensitivity an end-standard of approximately the same size as the cube was mounted between the jets. This standard comprised a cylindrical bar with flat and parallel end-faces to which three slip gauges were wrung side by side on one face to provide three known lengths in incremental steps of 0·00003 in. (0·75 μ). The supply pressure was adjusted to provide a constant pressure (P) equal to 5 lb/in.^{2} (0·35 kg/cm^2). With the tap (Fig. 2) in position (1) and the caliper positioned so that it embraced the central of the three lengths of the composite end-standard, the control orifice (a diaphragm-sealed needle valve) and the jet separations were adjusted to obtain an overall magnification* of about 20000. The actual value of the magnification was found by determining the change of reading of the indicating unit when the caliper was moved to measure in turn the two other lengths provided by the end-standard. The end-standard was then replaced by the cube and, with the control orifice unaltered, the jets were adjusted in relation to the cube faces to obtain approximately the same reading of the indicating unit as that found for the central length of the end-standard. During this adjustment the cube was kept symmetrically disposed between the jets, a condition readily attained by noting the change of reading produced when the rubber connexions were alternately pinched and moving the cube laterally until equal changes of pressure were shown. When these adjustments had been completed the clearance between jet and face of cube was about 0·0004 in. (10 μ) for each jet. Finally, the tap was turned to position (2) and the bleed valve set so as to obtain a chosen fiducial reading of the indicating unit approximately at mid-scale.

The variation of thickness of the cube was measured along each of the three principal axes in turn. Measurements were made in each direction using a regular 10 × 10 lattice, so that each face was divided into 100 squares of side 0·35 in. (9 mm) approximately and a measurement made at the centre of each square. Whilst the caliper was being traversed from square to square between measurements, the tap was kept in position (2) so that the observer, by watching the indicating unit, could check for sideways motion of the caliper and adjust the lateral position of the cube as required; when the measuring site was reached, the position of the cube was carefully adjusted to bring the reading of the indicating unit to the chosen fiducial value. The tap was then turned to position (1) and the measurement of thickness made. The complete set of measurements in each direction was repeated and the results "meaned." The values so obtained were combined with the interferometric measurements of the lengths of the edges to calculate the volume of the cube. As already mentioned, the value thus found for the volume agreed to rather better than one part in a million with that obtained from the optical interference measurements of the lengths of the edges and the contours of the faces relative to the corners.

CONCLUSION

The measurements described in this paper have establis that the pneumatic gauging technique will measure sm differences of length to an accuracy of ±1 μin. In ot work, it has been established that small displacements be measured to the same accuracy. Measurement to h precision is, however, but one application and, as mentio earlier, an important attribute of the technique is its flexibil It can equally well be used for measurements to 0·0001 or 0·001 in. and it has been successfully used at Laboratory to measure slip gauges, internal diamet variations in thickness of sheet material in motion, flat of photographic plates prior to use in the camera, chan in diameter of fine wires, etc. Some of these projects h been described in papers already published.(3,4,5)

It will have been noted that the measurement of the c was carried out without mechanical contact being made w faces; the measuring force at each jet was a few gram weight. This property of the method can in some app tions as, for example, in the measurement of relatively s objects, be of considerable advantage. In other ca where it may be advantageous to make direct mechani contact with the object being measured, pneumatic gaug may be used indirectly.(3)

ACKNOWLEDGEMENTS

The work described above has been carried out as part the research programme of the National Physical Laborat and this paper is published by permission of the Directo the Laboratory.

REFERENCES

(1) *National Physical Laboratory Annual Report*, p. (London: H.M. Stationery Office, 1953).

(2) Evans, J. C., Graneek, M., and Loe, H. G. "C tinuous pneumatic gauging of material in thread wire form." *Trans Soc. Instrum. Tech.*, **2,** p. 34 (19

(3) Evans, J. C., Marriner, R. S., and Morgan, I. G. sensitive comparator for measuring variation in c meter of wires." *Comp. Air Engng*, **17,** p. 313 (19 *Engineering* [*London*], **173,** p. 529 (1952); *Machin* **80,** p. 735 (1952); *Machinist*, **96,** p. 679 (1952); *W* *Industry*, **19,** p. 551 (1952).

(4) Evans, J. C., and Morgan, I. G. "A pneuma apparatus for measuring the flatness of photograp plates." *Engineering* [*London*], **180,** p. 510 (19 *Machine Shop Mag.*, **16,** p. 601 (1955); *Machinery*, p. 867 (1955); *Metalworking Production*, **99,** p. 1 (1955).

(5) Morgan, I. G., and Barnes, D. C. "A pneuma comparator for measuring variations in bore c meters." *Engineer*, **200,** p. 795 (1955); *Machine S* *Mag.*, **16,** p. 732 (1955); *Machinery*, **87,** p. 1377 (195 *Metalworking Production*, **99,** p. 2095 (1955).

---

* Measured as the ratio of the displacement of the pointer of the indicating unit to the change in length (or thickness) which produces it.

A simple scanning mechanism for X-ray diffraction

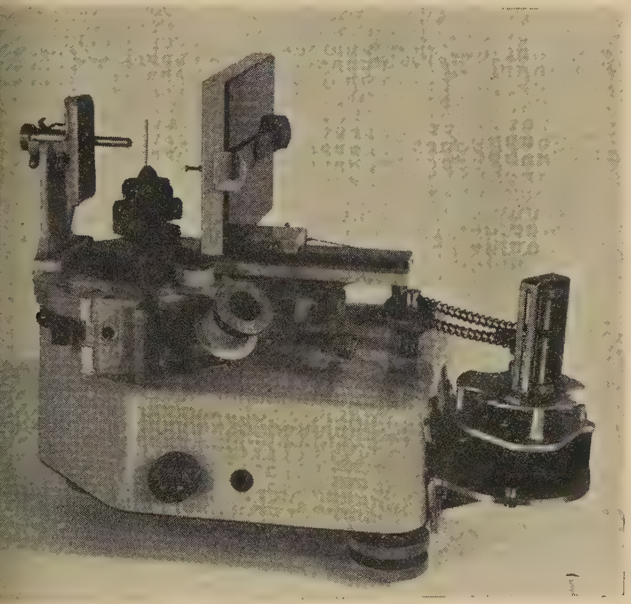
By G. W. Smith, M.Sc., A.Inst.P.,* and R. M. Hinde, B.Sc., Ph.D., A.R.I.C., A.Inst.P., British Insulated Callender's Cables Ltd., London, W.12

[*Paper received* 18 *May*, 1956]

A simple scanning mechanism is described for the X-ray investigation of preferred orientation in coarse-grained wires, by means of which the spottiness normally present in the diffraction patterns from such specimens is transformed into smooth variations of intensity on the Debye–Scherrer rings. The device is attached to a Unicam single-crystal goniometer and permits the non-repetitive scanning of a continuously rotating specimen. In its present form specimen lengths of about 5 mm can be scanned.

uring a recent investigation into the directional properties hard-drawn copper wire, some specimens were examined hich had been annealed at temperatures up to 500° C. he resultant grain growth which had taken place gave rise sharply defined spots on the Debye–Scherrer rings of the -ray transmission patterns, which made it impossible to etermine the presence of arcs of maximum density such as ere obtained with the hard-drawn material. A simple tation of the wire in the X-ray beam did not effect a suffient improvement and it was therefore necessary to scan ese specimens so that a larger number of grains could ontribute to the pattern to yield smooth continuous arcs.

A number of scanning devices(1–7) have been described the literature but have been primarily designed for the amination of flat plate specimens, while Mackay(8) has escribed a camera providing for a single scan of 3 cm of ire. The mechanism described below permits the connuous scanning of wire specimens and has the added dvantage of being fitted as an attachment to a standard nicam single-crystal goniometer, the necessary vertical otation movements being provided by the camera with the pecimen mounted on the crystal arcs.



Scanning mechanism mounted on single-crystal goniometer

The vertical motion is provided by a small self-starting ynchronous motor (No. 49606 by Smiths Clocks Ltd.) bolted to the camera as shown in the photograph, which provides a torque to the lifting screw on the goniometer by a short loop of Meccano chain. If the ratchet provided on the motor to give it a single direction drive is removed, it may be made to reverse automatically by giving a small impulse to the motor shaft. The driving shaft of the motor has a speed of 1 rev/min obtained by a 200 : 1 reduction gearing from the rotor shaft, and using a 1 : 1 drive to the lifting screw the specimen can be raised or lowered a distance of 5 mm in 5 min.

The reversing mechanism, which is supported on top of the motor, consists of a threaded ring moving along a threaded drum driven from one stage of the reduction gearing at a speed of 16 rev/min. The ring is prevented from rotating with the drum by a small guide arm moving in a vertical slot, and stops on the ring engage with adjustable end stops on the drum, thereby providing the necessary reversal impulse to the motor. The drum possesses a thread of 2 turns per mm, and a length of 5 cm is sufficient for a 5 mm scan.

This vertical motion, combined with the unidirectional rotation of the camera spindle, would ensure a non-repetitive scanning path over the whole surface of specimens of diameter greater than the width of the X-ray beam, unless a fortuitous phase relationship existed between the period of the reversal cycle and that of the rotation. If such a relationship were suspected, it could be eliminated by a slight alteration in the reversal period.

An upper scanning limit of 10 mm is imposed by the vertical motion incorporated in the goniometer and this may be achieved in two steps of 5 mm to prevent excessive misalinement of the chain drive at reversal. The necessary adjustment in the position of the motor is allowed for by the provision of slotted holes in the motor support.

ACKNOWLEDGEMENTS

Acknowledgements are due to Dr. L. G. Brazier, Director of Research and Education, British Insulated Callender's Cables Ltd., for permission to publish this note.

REFERENCES

(1) Barrett, C. S. *Symposium on Radiography and X-Ray Diffraction*, p. 200 (American Society for Testing Materials, 1936).

(2) Hay, R. H. *Rev. Sci. Instrum.*, **18**, p. 801 (1947).

(3) Hickman, J. W., and Kleinknecht, A. G. *Rev. Sci. Instrum.*, **20**, p. 573 (1949).

(4) Holmes, P. J. *J. Electronics*, **1**, p. 324 (1955).

(5) Thewlis, J., and Pollock, A. R. *J. Sci. Instrum.*, **27**, p. 72 (1950).

(6) Underwood, F. A. *J. Sci. Instrum.*, **29**, p. 128 (1952).

(7) Wainwright, C. *J. Sci. Instrum.*, **18**, p. 203 (1941).

(8) Mackay, A. L. *J. Sci. Instrum.*, **30**, p. 244 (1953).

---

* Now at British Petroleum Co. Ltd., Sunbury-on-Thames.

A simple vacuum leak detector using a radio-frequency mass spectr meter*

By P. F. Váradi, Ph.D., and L. G. Sebestyén, Research Institute for Telecommunication, Budapest, Hungary

[*Paper first received* 29 *December*, 1955, *and in final form* 29 *February*, 1956]

A simple vacuum leak detector, based on the radio-frequency mass spectrometer principle is described. In the pressure range of 10^{-3}–10^{-7} torr leaks of the order of $2 \cdot 8 \times 10^{-8}$ l. torr/s can be detected. The instrument may also be used as a conventional ionization manometer. A brief description of the principles and some details of the construction of the tube and of the portable electronic equipment are given.

As a Tesla spark coil cannot be used to find small leaks in a high vacuum system constructed of metal, or of metal and glass or ceramics, many other methods have been investigated and developed.$^{(1-3)}$ Of these the use of the mass spectrometer is most promising.$^{(4)}$ The principal drawbacks of the conventional mass spectrometer (even when adjusted to respond only to the search gas) are high cost and rather complicated maintenance. It is possible to build a very simple, but highly sensitive, leak-detector by using Bennet's type of radio-frequency mass spectrometer.$^{(5)}$ The design and construction of such a detector is described below.

The principle of Bennet's mass spectrometer may be briefly summarized as follows: an ion beam of high velocity is sent through a system of plan-parallel grids, similar to a linear accelerator. Alternate grids are grounded and the others have a radio-frequency voltage applied to them. If the time of transit of an ion between two grids is nearly half of the radio-frequency period, this particular ion gains energy from the radio-frequency field. All ions of the gas-mixture encounter a retarding potential barrier which allows only ions having the highest energy to pass through to the collector. As there is a relation between the charge/mass of the ions, the radio-frequency and the ion-accelerating voltage, the system can be used as a mass spectrometer.

THE LEAK-DETECTOR TUBE

In designing the radio-frequency leak detector, the following requirements had to be satisfied:

(i) pinhole leaks had to be detected in the high vacuum range (about 10^{-3}–10^{-7} torr†);

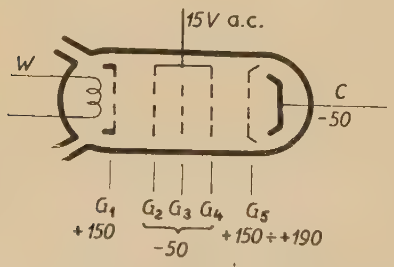


Fig. 1. Leak detector tube

W, *W*-cathode; G_1, grid of ion source; G_2, G_3, G_4, negative grids; G_5, retarder grid; *C*, collector

(ii) it had to be possible to use the instrument as a conventional hot-cathode ionization gauge;

(iii) the tube itself had to be inexpensive, simple, easy manufacture and de-gas, and suitable for building in any kind of high-vacuum system;

(iv) only a portable electronic equipment suitable for u in factories should be required.

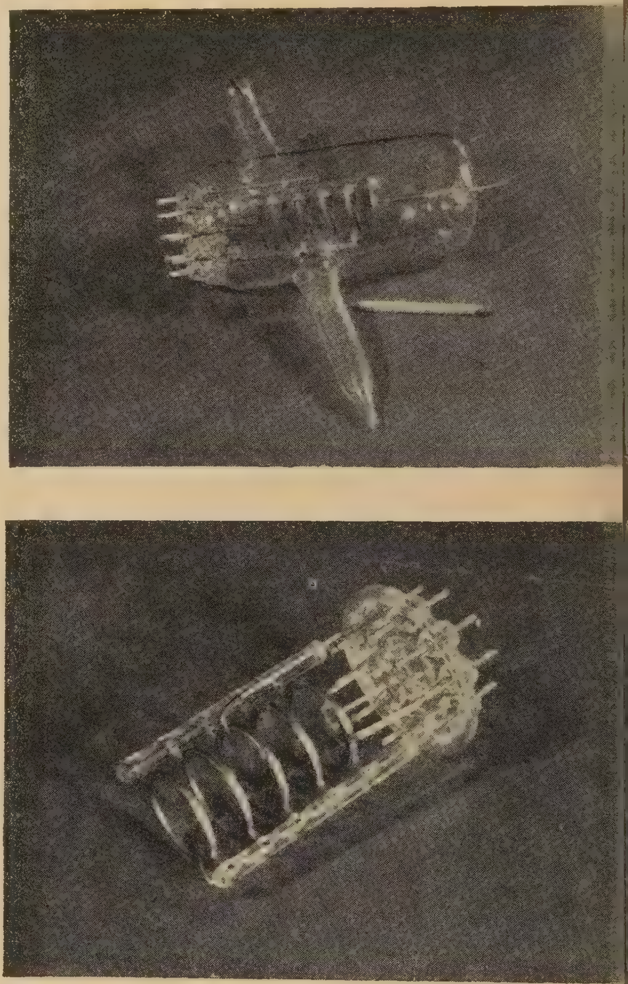


Fig. 2. Photographs of the leak detector

For good resolution it is essential that the ion beam shoul be monoenergetic; this involves a complicated ion sourc Using hydrogen or helium as search gases (the ion masses c which are very different from other gases contained in air a high resolution is not necessary. The length of the tube i determined by the fact that it has to be less than the mea free path of the hydrogen ions at the highest permissibl essure. Because of these reasons, five grids have been osen: the cathode and grid one form the ion source; grids o, three and four are negative with respect to the cathode, d on grids two and four a radio-frequency voltage is super- sed. Grid five, being positive with respect to the cathode, rms the retarding potential barrier. The collector is parated from the grids on the top of the tube (Fig. 1).

---

* Based on a lecture presented at the first annual meeting of the Society of Radio Engineers, Budapest, May 1954.

† 1 torr = 1·333 22 mb and is equal to the conventional barometric millimetre of mercury, within one part in seven million.

Great care was taken to keep the metal parts of the tube a minimum and to avoid the use of ceramics; in earlier bes, where a distance-ring of steatite had been used, irtual leaks” were observed. The grids spaced at 7 mm stance from each other, are wound with twenty loops per ntimetre. The *W*-wire has a diameter of 0·03 mm, and e grid is mounted on a nickel frame. The frames are held two glass rods; this construction makes it possible to keep e grid distances within narrow tolerances. The frames ve a diameter of 18 mm; the tube is 70 mm long and has diameter of 35 mm.

The grids near the hot cathode are gold-plated. The mperature of the pure *W*-cathode is about 2000° K and W heating power is needed for 5 mA emission current. otographs of the tube are shown in Fig. 2.

ELECTRONICS

The electronic circuit may be divided into three parts.

Firstly, the emission stabilizer (Fig. 3), which must keep e emission constant when the line voltage and the gas essure in the tube vary. If the electron current of the k detector deviates from the prescribed value, the deviation uses the voltage drop more or less on resistance R_k which gulates the plate current of V_3. This change of current uses a change in the heater voltage of the leak detector be, re-establishing the original emission current. The ay in the circuit of V_3 breaks, if the pressure in the spectro- ter tube becomes higher than the prescribed value, thus otecting the heater.

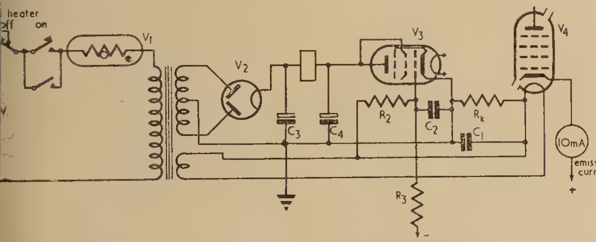


Fig. 3. Circuit of emission stabilizer

R_2, R_3 = 0·1 MΩ
R_k = 20 kΩ
C_1, C_2 = 0·1 μF
C_3, C_4 = 16 μF

V_1 = baretter
V_2 = AZ41
V_3 = EL41
V_4 = leak detector tube

Secondly, a d.c. feedback amplifier is used to detect the current. A pentagrid converter is used with 4 V heater tage, the third grid being the signal grid. The input istor is at maximum at 3×10^8 Ω, and full-scale deflexion the output meter corresponds to 8×10^{-10} A (Fig. 4).

Lastly, a conventional tuned-grid type oscillator produces radio-frequency voltage. At the chosen d.c. potentials d grid distances, a value of *f* equal to 7 Mc/s is needed for drogen gas. The amplitude of the radio-frequency voltage 15 V. Special amplitude and frequency stabilization did seem necessary.

PERFORMANCE

The method of leak location is the conventional one: a jet hydrogen gas is passed over the surface of the vessel under test and its entry through the leak is indicated by a moving-coil instrument. The response time constant is very short; at leaks greater than about 10^{-7} l. torr/s there was practically no time lag.

The resolving power of the leak detector—using the $M/\Delta M$ definition where ΔM is the peak-width at half height—is about five for hydrogen gas with the voltages shown on Fig. 1. It was found that leaks of the order of $2 \cdot 8 \times 10^{-8}$ l. torr/s (0·1 μl./h) could quite readily be detected. With a hydrogen to air mixture of 1 : 1000, ion current of 4×10^{-10} A was obtained, corresponding to half-scale deflexion of the ion current meter. As it was conveniently possible to make use of even 5% of full-scale reading, the ratio of minimum detectable hydrogen pressure to air pressure was about 1 : 10 000.

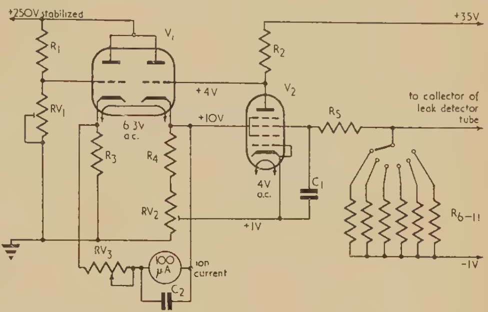


Fig. 4. Circuit of ion current detector

R_1 = 0·12 MΩ
R_2 = 5 MΩ
R_3 = 4 kΩ
R_4 = 3 kΩ
R_5 = 0·1 MΩ
R_6–R_{11} = 3×10^8 Ω

C_1 = 100 pF
C_2 = 1 μF
V_1 = ECC40
V_2 = 6BE6

The radio-frequency spectrometer tube may be built into any vacuum system where the leak is to be detected, and no separate pump is needed.

If the pressure in the investigated system is higher than a prescribed value, a background is produced in the ion-current of the collector. This means that ions originating from residual gas components are able to gain sufficient energy to reach the collector; we are assuming that a part of the background is composed of secondary and reflected electrons. In the early experiments an attempt was made to eliminate the background by using higher retarding potential and a separate suppressor grid; this caused a loss in sensitivity. The d.c. compensating of the background proved to be more successful in obtaining the sensitivity already mentioned.

As an ionization manometer, grids G_2–G_5 are connected together and ion current on collector *C* is measured.

CONCLUSION

With the help of a relatively simple tube and electronic circuits an instrument was constructed which has proved to be an effective tool in finding leaks in high vacuum equipment in the pressure range of 10^{-3} to 10^{-7} torr. If the leak detector is built together with a separate pump, and a more sensitive detector for ion current is used, then it seems possible to attain the sensitivity reached by magnetic mass spectrometer leak detectors.

ACKNOWLEDGEMENT

The authors wish to acknowledge their appreciation to Dr. E. Winter, head of the Laboratory, for his inspiring guidance and many helpful suggestions.

REFERENCES

(1) Dushman, S. *Vacuum Technique*, p. 370 (New York: J. Wiley and Sons, Inc., 1949).

(2) Ochert, N., and Steckelmacher, W. *Vacuum*, **2**, p. 125 (1952).

(3) Barnard, G. P. *Modern Mass Spectrometry*, p. (London: The Institute of Physics, 1953).

(4) Nier, A. O., Stevens, C. M., Hustrulid, A., Abbot, T. A: *J. Appl. Phys.*, **18**, p. 30 (1947).

(5) Bennet, W. H. *J. Appl. Phys.*, **21**, p. 143 (1950).

An instrument for the continuous measurement of shrinkage of textile yarns

By R. A. E. Ellis, M.A., A.M.I.E.E., Imperial Chemical Industries Ltd., Millbank, London, K. W. Hillier, Ph.D., and A. B. Thompson, B.A., Imperial Chemical Industries Ltd., Fibres Division, Harrogate

[*Paper received* 25 *June*, 1956]

The yarn is fed from a bobbin at a fixed rate into a hot-air treatment chamber. After passing over a tensioning device it is withdrawn at a variable rate so that the tension and length of yarn in the chamber (and therefore the time of heat treatment) are held substantially constant. The tension is known and adjustable. The shrinkage under these controlled conditions is derived from the ratio of input to output rates, and is displayed numerically as a percentage. After a bobbin has been knotted in and the instrument started, a fixed length of yarn is tested automatically.

In the course of research on the production and testing of Terylene polyester yarn, it became necessary to measure the shrinkage of textile yarns when subjected to thermal treatment under very low tension. The traditional method of making this measurement is to wind the yarn under a fixed tension to a loop of known size and allow it to shrink freely under the thermal treatment; its length is measured before and afterwards. That method is intermittent, it only gives the mean shrinkage over a long length of yarn, and, in order to cope with many samples in the laboratory, a batching method is necessary so that a long time elapses before an individual result becomes available.

It was required to know not only the average shrinkage (expressed as a percentage length change suffered by the yarn) but also to have some estimate of the variation in shrinkage along the length of yarn contained on a bobbin and the variation between bobbins of ostensibly identical make. The machine to be described has been used successfully to carry out measurements of the shrinkage of continuous filament Terylene polyester yarn when subjected to a heat treatment of 100° C for one minute at a very low predetermined tension.

The basic principle is to feed the yarn into a hot air chamber at a constant rate and under constant tension, and to feed it out, after treatment, at a rate controlled by the length under test, which is thus kept substantially constant. The feed-in rate is such that any portion of the yarn is within the hot chamber for one minute. The percentage shrinkage can be deduced from a knowledge of the differential input and output speeds of the yarn, and this result is presented digitally.

DESCRIPTION OF THE MACHINE

It must be emphasized that, for reasons to be described below, the actual machine is rather more complicated and differs slightly in principle (particularly regarding the gears, cams, and switches) from the following description and illustration; differences have only been introduced to present a consistent and simplified explanation.

Referring to the figure, yarn from the package (1) to be tested passes through a ball tensioning device (2) and is drawn at constant speed between a pair of rolls (3) driven by an electric motor (4). One of the rolls is rubber cove is free running, and pressed on to the driven roll. The y

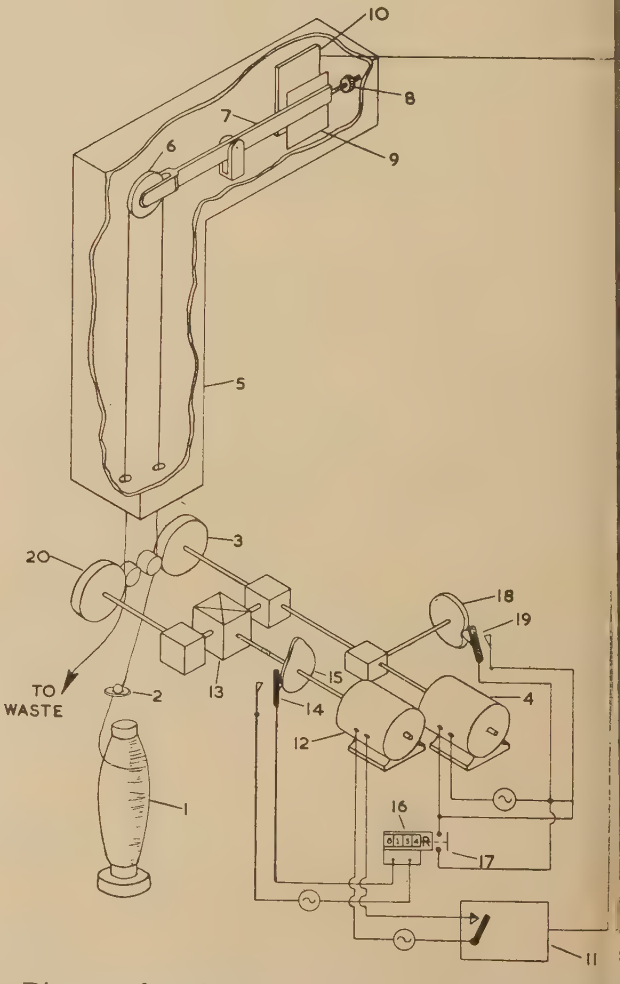


Diagram of continuous shrinkage measuring instrumen en passes through the heated chamber (5), over a freely tating pulley (6) pivoted on a balance arm (7), and then tween a second identical pair of rolls (20) and so out of e machine to waste. The metallic balance arm (7) is ounted on a pivot located at the same height as the centre gravity of the balance arm when horizontal. An adjustable ight (8) is mounted on the balance arm as well as a vertical etallic plate (9). The balance can therefore be adjusted so at, when horizontal, a known tension is applied to the rn. Adjacent to the plate (9) is another metallic plate (10) ich is so disposed that a clockwise motion of the balance m causes a reduction in electrical capacity between the o plates, which is detected by the capacity relay (11). hen energized, this causes the electric motor (12) to operate, d its motion has two effects. Firstly, it introduces a tational motion in the differential (13), thereby subtracting om the rotational speed of rolls (20). Secondly, at every volution of the motor (12), the contacts (14) are closed ce by the cam (15), and the electromagnetic counter (16) vances by one unit.

The machine is started by pressing button (17), which arts the motor (4) and simultaneously zeroes the counter 6) by a mechanical connexion to its reset mechanism. As on as the cam (18), driven from the motor (4), has lifted e contacts (19) from its indent, the button (17) can be leased.

Suppose that the yarn does not shrink. The balance m (7) will be horizontal, capacity relay (11) not energized, otor (12) stationary, no additive motion introduced into e differential (13), rolls (3) and (20) rotate at identical speeds, and the yarn is fed into, and out of, the hot air chamber at the same linear speeds.

If, however, the yarn shrinks, balance arm (7) rotates anticlockwise, capacity relay (11) is energized, motor (12) rotates, rolls (20) rotate more slowly than rolls (3) and less length of yarn is fed out than is fed in; the balance arm is thus restored to its horizontal position. The difference in speeds between rolls (20) and (3), and thus the shrinkage of the yarn, are clocked up by the counter (16). The machine automatically stops when the contacts (19) fall into the indent in cam (18); the gear ratios and diameter of roll (3) decide the length of yarn which has been tested, and it can easily be arranged, by adjustment of these, that the reading on counter (16) is numerically equal to percentage shrinkage.

The balance arm (7) only deviates slightly from horizontal; the tension in the yarn is proportional to the cosine of the inclination of this arm, and so is substantially constant.

In the actual machine auxiliary contacts and relays are provided to render it more completely automatic. The operator is merely required to knot in a new bobbin of yarn and to press a reset button momentarily. After a known length has been tested an alarm bell sounds to draw the attention of the operator, and the machine stops with the counter registering the percentage shrinkage. A waiting time is incorporated, so that the residue of yarn left in the system from a previous measurement has been eliminated before a fresh measurement commences.

In another version of this instrument, variations in shrinkage along the bobbin were automatically recorded by means of a periodically tripped Huyghens endless chain mechanism.

A portable instrument for respirable dust sampling

By R. J. Hamilton, B.Sc., A.Inst.P., National Coal Board, Mining Research Establishment, Isleworth, Middlesex

[*Paper received* 1 *June*, 1956]

Dust-laden air is drawn into the instrument, which is known as the long running thermal precipitator, by means of a clockwork-driven diaphragm pump. Passage through a horizontal elutriator removes all but the respirable fraction which is then deposited on a single horizontal microscope slide by a combination of gravity settlement and thermal precipitation.

A single sample covers up to eight hours operation, giving a measure of average dustiness. Evaluation is normally by visual microscopy, but the method of collection employed provides a deposit particularly well suited to bulk evaluation techniques.

The instrument is "intrinsically safe" for use in gassy coal-mines, self-contained, and simple to operate. Extended pit trials have proved it to be robust and reliable and to give results in agreement with those obtained by the conventional thermal precipitator.

requirement for an airborne-dust sampling instrument apable of unattended operation over long periods, and roviding a sample of respirable dust, has arisen from two auses, firstly, the awareness that the health hazard is related the total quantity of dust breathed into the lungs over long eriods,(1) and, secondly, the high manpower requirements of dust sampling programme such as that carried out by the ational Coal Board, if conventional dust sampling instruents are employed.

The new instrument, which is known as the "long-running iermal precipitator" has been designed to operate over eriods of up to eight hours (one working shift). It is to be ft at a fixed point during this time; in a coal mine, for xample, this fixed point might be at the "return" end of the oal face, a place where, in general, dust concentrations are igher than elsewhere along the face.

Only the respirable dust, which is selected aerodynamically from the total airborne cloud during the sampling process, is collected. The selection of this fraction is effected by drawing the dust-laden air through a horizontal duct elutriator, the action of which simulates that of the human nose and upper respiratory passages in which the removal of the largest, fastest falling particles is due to the processes of settlement and impingement.

PRINCIPLES OF OPERATION

The instrument collects dust by a combination of gravity settlement and thermal precipitation.(2) This method avoids the weaknesses of both the conventional thermal precipitator and the simple sedimentation sampler, end makes use of their advantages.

Despite its practical disadvantages of limited sampling time and difficulty of manipulation, the original thermal precipitator(3) has retained its place as a standard dust sampling instrument because all the particles are deposited in their original form. The limitation in sampling time of the instrument is due not only to the deposition of dust in a small area, but also to the obscuration of a high proportion of this area by relatively few large particles. The maximum density on a slide which can be counted depends on the projected area of particles in the deposit.

Study of thermal precipitator records of underground airborne coal dust clouds indicates that the projected area of particles finer than 5 μ (conventionally taken as the top size of "respirable" dust particles) comprises only a small fraction (about 10%) of the total projected area of dust in the deposits. Fig. 1 shows the surface area distribution of a typical dust cloud calculated from the numerical distributions given by Wynn and Dawes.(4)

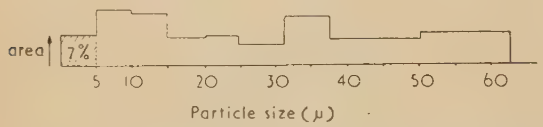


Fig. 1. The projected area distribution of dust in a typical thermal precipitator sample from a Yorkshire pit

The new instrument can be operated for a much longer time than the conventional thermal precipitator because, firstly, the collection area is considerably greater (0·25 in.^{2} against 0·02 in.^{2}), secondly, the largest (non-respirable) particles are eliminated by the "size selector," and, thirdly, the large and small respirable particles are deposited separately.

The dust-laden air, after passing through the size selector, is drawn over a single horizontal collection surface (a microscope slide) on to which the particles are deposited by gravitational settlement and, at a later stage, also by thermal precipitation. The larger, faster-falling particles are all deposited by gravitational settlement in the first part of the area, so that the top size of particle is reduced progressively along the slide until, in the thermal precipitation zone, all the remaining airborne particles are deposited. The dimensions of the channel and rate of air flow are such that only particles with a falling speed less than that of a 3·25 μ unit density sphere (equivalent to 3·5–4 μ coal dust) penetrate as far as the thermal precipitation zone. Fig. 2 shows how particle surface (of a sample with the size distribution sh in Fig. 1) is distributed along the deposit.

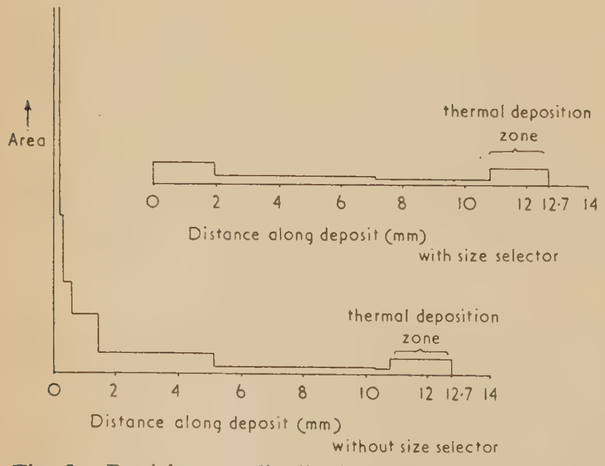


Fig. 2. Particle area distribution along sampling area (given by sample from cloud of distribution shown in Fig. 1)

The principle of one-sided thermal precipitation is not n Beadle and Kitto have described an instrument working this principle.(5) Their device, which is designed as a sh period sampler, however, involves the collection of dust a vertical surface and does not involve any collection settlement.

The horizontal elutriator size selector is of the t described by Walton.(6) It is designed, at the standard fl rate, to remove from the inspired dust cloud all those parti with a falling speed greater than a 7·1 μ (5$\sqrt{2}$ μ) unit den sphere and 50% of particles with a falling speed equa that of a 5 μ unit density sphere. Fig. 3 shows the p

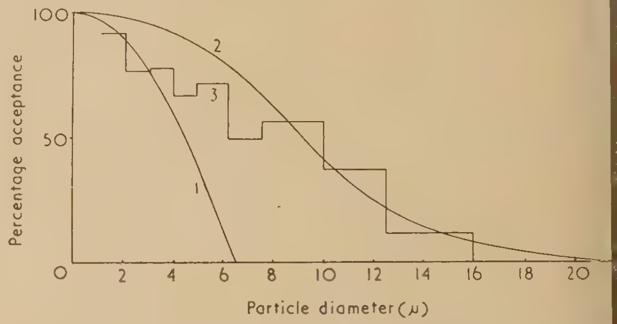


Fig. 3. Horizontal elutriator performance: (1) theoretical, for spheres density 1·3, (2) theoretical for coal taking account of relationships between falling speed and particle size, and (3) experimental results with coal dus

formance of this selector with spheres and with coal d particles. Panel 1 of the Medical Research Council Indust Pulmonary Diseases Committee have recommended that su a selection process be regarded as a standard method "respirable" dust sampling.

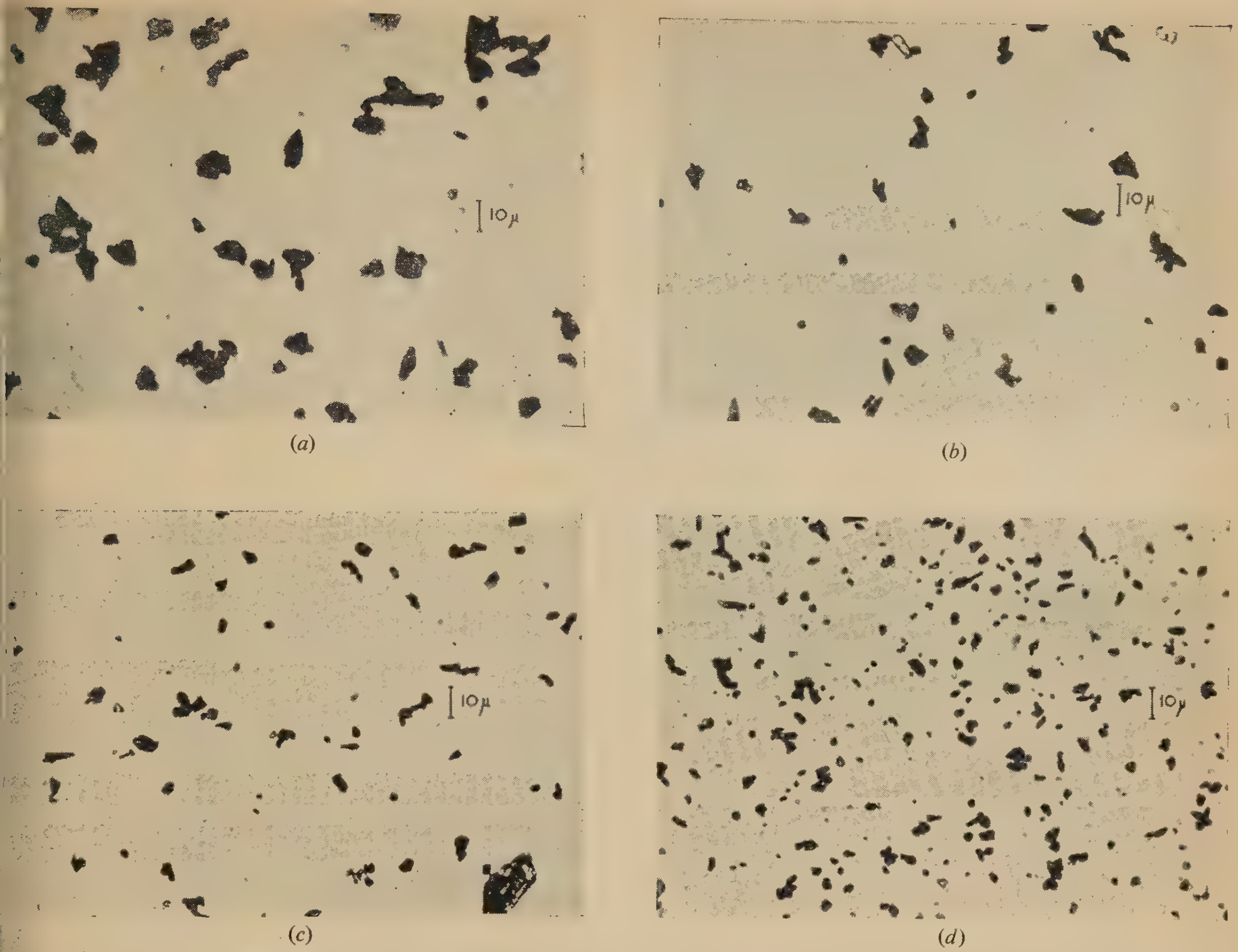
The photomicrographs in Fig. 4, from an undergrou sample, show the variation of diameter of coal dust partic with distance from the end of the deposit.

DESCRIPTION OF THE INSTRUMENT

The complete instrument, which is depicted in Figs. 5 and comprises the sampling head, the power supply componen and the mechanical pump.

The sampling head consists of a light alloy block with insert of Tufnol laminated-paper based plastic to support heating element.

A diagram of the head is shown in Fig. 7. A standa 3 × 1 in. microscope slide, or $\frac{7}{8}$ × 2 in. coverslip mount in a special holder, is mounted rigidly below the block, a dust is collected over an area 0·5 in. square. The heati element is held in a groove milled in the Tufnol insert a consists of 36 s.w.g. Nichrome wire held rigidly by berylliu copper springs. The lower edge of the wire is held flush w the bottom of the insert, whilst the insert is supported 0·007 from the collecting surface by two Paxolin spacing piec The air-channel above the collecting surface is kept 0·007 deep over some distance, so that the deposit remains v uniform over its width. Owing to a certain amount of heati up of the plastic in the neighbourhood of the element, t thermal deposition zone is considerably wider (rather m than 2 mm) than in the conventional thermal precipitat This is an advantage, since it spreads out the deposition the finest particles.



(a) (b) (c) (d)

Fig. 4. Photomicrographs of dust at positions (*a*) 0, (*b*) 6, (*c*) 10 mm from start of deposit, and (*d*) in thermal precipitation zone

The size selecting channel on top of the sampling head is designed that coarse dust settling in the channel cannot dily be shaken on to the collecting microscope slide. The ver-plate of the elutriator can be swivelled to one side so t the floor of the channel can be cleaned between sampling fts. A simple "umbrella" cover is fitted over the sampling fice, to give protection from fall-in of very large particles l water drops.

The power supply assembly consists of a miner's hand-lamp tery (nickel cadmium by Nife Batteries Ltd.). A 1·5 A e and 0·3 Ω limiting resistor are housed in the top of the tery compartment and the remaining circuit components nprise a 1 A fuse, switch, ammeter, pre-set rheostat, and heating element. The rheostat is set so that the fully rged battery passes a current of 1·0 A. This current drops ring the working period, but as long as the current does not below 0·8 A, the element temperature remains high ugh to give efficient precipitation.

The mechanical pump assembly (*B*, Fig. 6) consists of a ple valveless diaphragm pump operated by a "linear tion cam." The swept volume of the pump is adjusted to cm³, and this volume of air is drawn in through the npling head over thirty seconds, and blown out, again ough the sampling head, during the following thirty onds. The "dead" volume of the sampling head is small 2 cm³). From experimental work, it has been found that any error introduced by this is negligible. A cross-section of the pump and cam is shown in Fig. 8. It will be seen that the swept volume of the pump can be varied between narrow limits (±5%) by movement of the pump body backwards and forwards in relation to the cam. This involves a slight, but unimportant, lack of linearity in the airflow rate. The linear motion cam consists of a left-handed half helix and a right-handed half helix, joined together. The cam is rotated by a robust clockwork motor with fusee drive and Jeanneret escapement (by F. W. Elliott Ltd.).

The instrument case is constructed of 19 s.w.g. steel and consists of two compartments; one, which is secured by a magnetic lock, holds the battery, and the other the sampling head and pump mechanism. The latter compartment is accessible from the hinged top which is secured by a cylinder lock and is opened above ground only.

A door in the side of the instrument covers a Perspex panel through which may be seen an ammeter indicating element current, a clock face with hour hand to show running time, and the clock escapement. The Perspex panel is attached to the clockwork drive and pump unit, and the square boss for winder key and the on-off control protrude through it. The latter control operates both the clockwork and the heating circuit. A simple bubble flowmeter is provided to enable users to check the flow rate from the pump.

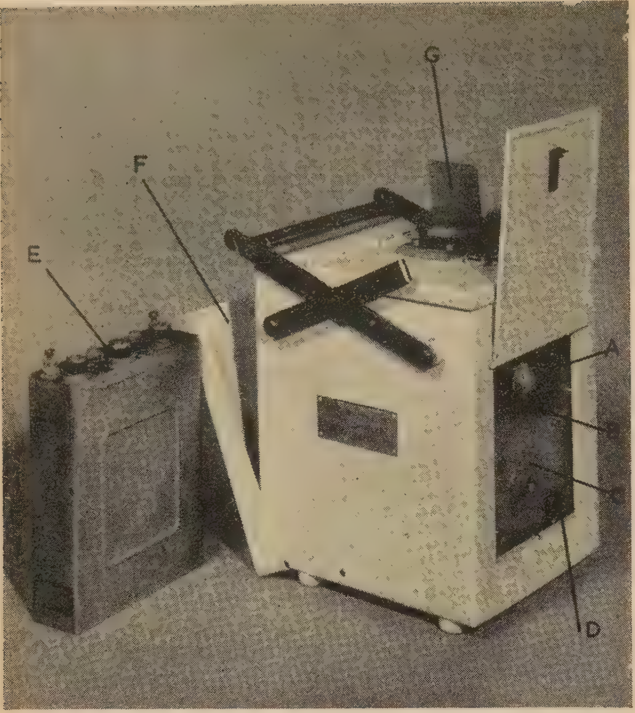


Fig. 5. View of thermal precipitator: *A*, ammeter; *B*, on-off switch; *C*, running-time indicator; *D*, winding boss; *E*, battery; *F*, battery compartment lid; *G*, umbrella, lifted to show sampling orifice

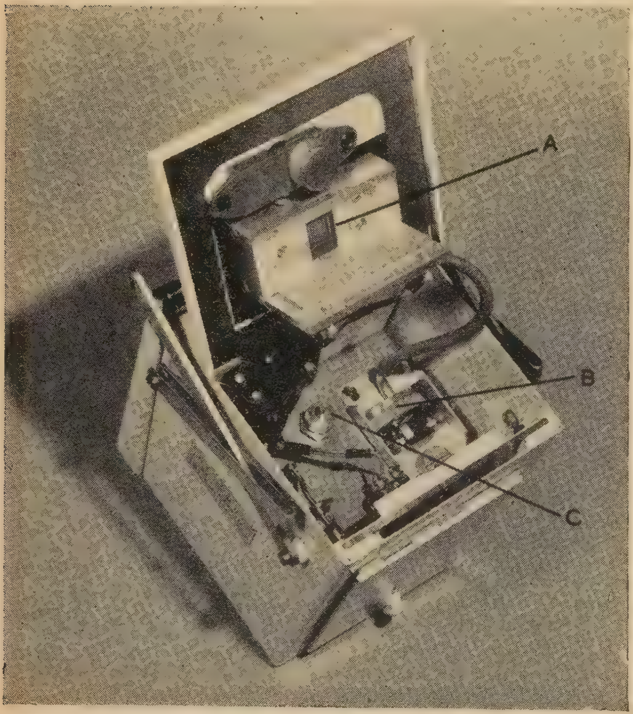


Fig. 6. Interior of thermal precipitator: *A*, thermal precipitation element; *B*, diaphragm pump; *C*, pre-set rheostat control

THE EVALUATION OF DUST SAMPLES

The evaluation of samples is normally carried out by v microscopy, taking a single traverse over the deposit; th justified by the great uniformity of deposit over its w owing to the design of air channel and the use of a r protected, heating element. When the dust has been colle on a microscope slide, it is customary to use a 4 mm objective for examination and an eyepiece graticule of type described by Hamilton, Holdsworth and Walton,[7] microscope tube-length adjusted so that the traverse widt 60 μ. When the dust has been collected on the cover either a 4 mm dry, or a 2 mm oil-immersion objective ca employed. In the latter case the graticule width is adju to be 30 μ. It is essential that coverslip collection and immersion microscopy be used when evaluation of rock samples down to $0 \cdot 5$ μ is required.

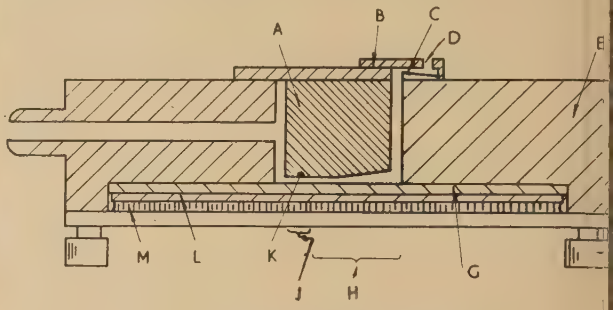


Fig. 7. Section through sampling head

A, Tufnol "insert"; *B*, swivelling top plate; *C*, selecti channel; *D*, entry orifice; *E*, light alloy block; *F*, captive bolt *G*, slide or coverslip holder; *H*, gravity settlement zon *J*, thermal precipitation zone; *K*, heated element; *L*, me backing plate; *M*, sponge rubber pad.

The calculation of particle concentration is readily obta from the expression:

$$N = nW/Vw$$

where N = airborne concentration (particles/cm^3)
n = number of particles counted in traverse
W = width of deposit (about 12 700 μ)
V = volume of sample (cm^3) (numerically equa time in minutes $\times 2$)
w = width of traverse (μ).

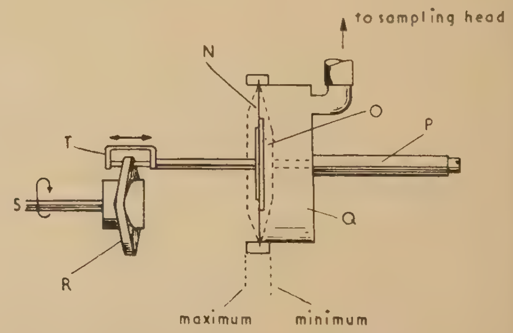


Fig. 8. The diaphragm pump, with diaphragm in mid position (not to scale). Maximum and minimum indica the swept volume adjustment

N, latex diaphragm; *O*, centre plates; *P*, bearing; *Q*, pum body; *R*, linear velocity cam; *S*, clockwork drive; *T*, ca follower.

hen there are a large number of particles on the slide, only rticles lying in a traverse of one-third of the width of the aticule grid are counted (20 or 10 μ for the 4 mm and 2 mm jectives, respectively).

Since a horizontal duct elutriator with a standard cut-off rve is incorporated in the instrument, instead of making unts in the conventional size ranges of 1 to 5 μ and 0·5 to μ for coal and rock dusts respectively, particles greater than μ and greater than 0·5 μ are counted in the two cases.

At the time of writing, an alternative rapid sample evalua- on technique is under development. This is made possible the size-segregation of the particles in the deposit, and the evious removal of the non-respirable fraction. The tech- que involves the measurement of optical density of the posit in a number of narrow transverse strips. In each ip the mean size of particle is known, and the optical nsity may be related to the number, surface, or mass of rticles therein.

RESULTS OF UNDERGROUND TESTS

The instrument, after inspection, was passed as intrinsically fe for use in gassy coal mines by H.M. Chief Inspector of ines. A number of instruments have been used in coal ines for rather more than a year. They have proved capable withstanding the normal rough usage received underground, d have been commented on favourably by the various users.

Tests of collection efficiency have consisted of operating e new instruments alongside a conventional thermal ecipitator. The long running instrument was operating ntinuously during the sampling period, while a number sually eight) of short period samples were obtained with the standard instrument. Some results obtained in the underground tests are illustrated in Fig. 9; here measurements of coal-dust cloud concentrations given by the new instrument, and by the standard thermal precipitator, are plotted on the y and x axes respectively. It will be noted that the two instruments are, in general, giving the same estimate of dust concentration, as indicated by the symmetrical grouping of results about the 1 : 1 line. There is, however, considerable scatter of individual results, due mainly to the inaccuracies of long period mean concentration estimation by the standard thermal precipitator, owing to its limited coverage, but also to the inevitable inhomogeneity of the sampled cloud and to the errors introduced in the sample assessment processes. It is of interest to observe that the average concentrations measured in coal-dust clouds (172 shifts) by the two instruments were: new instrument 364 particles/cm^3 (greater than 1 μ), and standard thermal precipitator 368 particles/cm^3 (1–5 μ). In rock-dust clouds (forty shifts) the corresponding figures were 743 particles/cm^3 (greater than 0·5 μ) and 747 particles/cm^3 (0·5–5 μ) respectively.

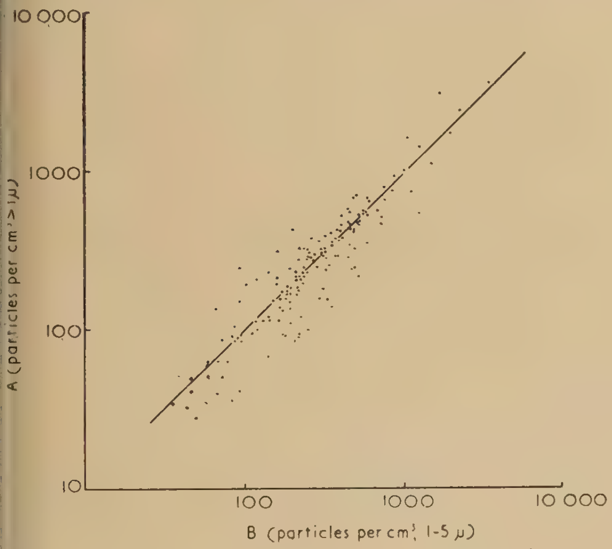


Fig. 9. Comparison of shift mean concentrations as measured by the long-running thermal precipitator, *A*, and the standard thermal precipitator, *B* (coal dust)

ACKNOWLEDGEMENTS

The thanks of the author are due to a large number of people in the Mining Research Establishment who have been associated with the design and development of the instrument, particularly to Mr. W. H. Walton, Assistant Director, and to Mr. A. E. Bennett, Head of the Instrument Branch, who with the following members of that branch, Messrs. H. Spiller, K. Rumsey and J. Senior, has been responsible for the engineering development. Mr. D. Hicks, Director of Scientific Control, National Coal Board, and the Scientific Control Staff concerned in the underground trials have given the greatest help and encouragement.

The work described in this article forms part of the research programme of the Mining Research Establishment, and is published by permission of Dr. W. Idris Jones, Director-General in the Scientific Department of the National Coal Board. The views expressed are those of the author and not necessarily of the Board.

REFERENCES

(1) Wright, B. M. *Brit. J. Industr. Med.*, **10**, p. 235 (1953).

(2) Rosenblatt, P., and La Mer, V. K. *Phys. Rev.*, **70**, pp. 385–95 (1946).

(3) Green, H. L., and Watson, H. H. *Medical Research Council Special Report Series*, No. 199 (London: H.M. Stationery Office, 1935).

(4) Wynn, A. H. A., and Dawes, J. G. *Safety Mines Res. Establ. Res. Rep.*, No. 28 (1951).

(5) Beadle, D. G., and Kitto, P. A. *J. Chem. Met. Min. Soc. S. Africa*, **52**, p. 284 (1952).

(6) Walton, W. H. *Brit. J. Appl. Phys.*, *Suppl.* 3, **5**, p. S 29 (1954).

(7) Hamilton, R. J., Holdsworth, J. F., and Walton, W. H. *Brit. J. Appl. Phys.*, *Suppl.* 3, **5**, p. S 101 (1954).

Laboratory and workshop notes

Preparation and maintenance of spherical metal electrodes in hydrogen

By J. O'M. Bockris, Ph.D., D.Sc., F.R.I.C., B. E. Conway, Ph.D., A.R.I.C., and W. Mehl, Ph.D., University of Pennsylvania, U.S.A.

[*Note received* 21 *February*, 1956]

Methods for sealing wires into glass tubes in hydrogen and maintaining them in this gas until used as cathodes in electrolysis studies have been described.(1, 2)

In alternating current measurements of electrode double-layer capacity and metal deposition kinetics, a uniform radial distribution of current lines between a large non-polarizable electrode, e.g. of platinum, and the test electrode is required. To achieve this the test electrode must be predominantly spherical in shape. In order to obtain a pure and new smooth surface it is desirable to be able to melt the metal in hydrogen.

Previous methods of preparation of pure solid electrode surfaces(1,2) have therefore been modified so that spherical electrodes may be prepared by fusing the metal in purified hydrogen. An arsenic-free Pyrex glass tube about 4 mm diameter is used to form the electrode holder and thin glass bulb as shown in Fig. 1(*a*) and 1(*b*). This tube and bulb is sealed to a 10 mm standard taper joint which is connected to a corresponding joint of the same size but made of clear fused silica.

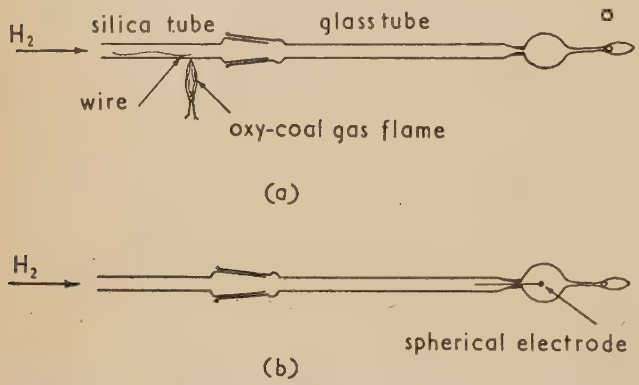


Fig. 1. Showing use of arsenic-free glass tube in forming electrode holder and thin glass bulb

A $2\frac{1}{2}$ cm length of the test metal, in the form of wire 0·013 cm diameter, degreased by washing in redistilled petroleum ether, is inserted by platinum-tipped tweezers into the silica tube which is then connected to the hydrogen purification train. Hydrogen is passed through and burns at the orifice o in Fig. 1(*a*). After several minutes a small oxy-coal gas flame is applied to the outside of the silica tube at one end of the wire. The wire fuses at its end in the hydrogen stream and a ball of fused metal forms and passes down the wire. The size of the fused ball of metal can readily be controlled by the time of application of the hot flame. Spheres up to 1 mm diameter on the end of 0·013 cm. diameter wires can be obtained.

The wire with the spherical end is then passed down to the end of the Pyrex tube into the thin bulb and carefully sealed to the glass in the hydrogen atmosphere [Fig. 1(*b*) and Fig. 2], as described previously.(1) Further treatment by a.c. induction heating(2) may also be carried out if required.

In addition to giving solid electrodes of the required f for a.c. impedance measurements, the method enable completely new metal surface to be formed and maintai

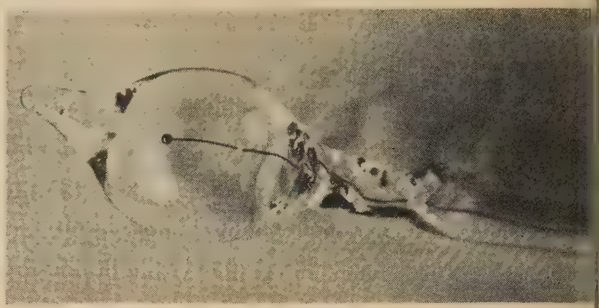


Fig. 2. Spherical electrode sealed into glass bulb i hydrogen. (For clarity an unusually long length of wir is shown)

in hydrogen. Microscopic examination of the electro shows them to have an extremely smooth specular surf Electrodes prepared similarly in helium are less smooth specular and give less reproducible electrode capacity res than the electrodes prepared in hydrogen.

The authors wish to acknowledge gratefully a grant fr the American Electroplaters' Society in support of work the kinetics of metal deposition.

REFERENCES

(1) Bockris, J. O'M., and Conway, B. E. *J. Sci. Instru* **25**, p. 283 (1948).
(2) Pentland, N., Bockris, J. O'M., and Sheldon, *J. Sci. Instrum.*, **32**, p. 364 (1955).

Conical ground joint extractor

By S. G. Yorke, Department of Chemistry, University Bristol

[*Note first received* 12 *March, and in final form* 1 *May* 1956]

Conical ground glass joints constitute a convenient coupl between the separate parts of scientific glass apparatus. It however, a matter of experience that joints of this nature many cases tend to become firmly jammed in the course normal use as a result, for example, of temperature chang of chemical deposits or of prolonged evacuation of apparatus. Attempts to part the joints so affected by tapp or twisting often result in the breaking of the apparatus a the loss of its contents.

An extractor is described, which, being constructed on principle of an engineer's wheel drawer or sprocket remov will apply a mechanically controlled thrust and pull opposite directions to the two sections of a ground joint a effectively part them after other methods have failed. Ba cally, the device consists of a headpiece, to which th adjustable legs are attached, and a rod which is retracted extended through the head by means of a screw arrangeme In use, some form of catchpiece which engages with the co section of the affected ground joint is attached to the r hile the legs of the headpiece are positioned to engage with e socket section of the joint. By turning the screw, a rust and pull is applied to the socket and cone respectively, *vice versa* according to the mode of application. Some pplications of the extractor are illustrated diagrammatically Fig. 1.

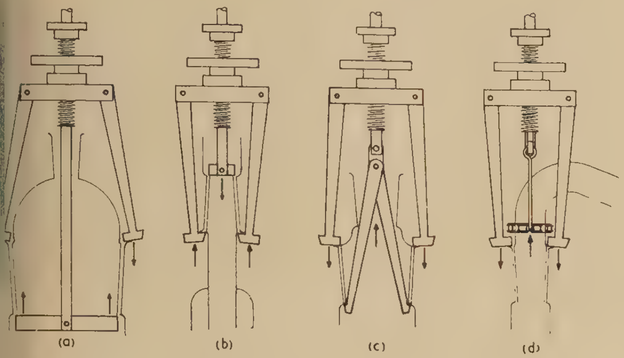


Fig. 1. Some applications of extractor

The removal of a glass adaptor which incorporates a small int on a large cone and has no convenient external gripping rface is shown in Fig. 1(*a*). A catchpiece, consisting of a ip of metal with a hole through the middle, is attached to e end of the rod so that it is free to swivel, thus permitting insertion through the small joint and, by subsequent anipulation the catchpiece engages the smaller end of the rge cone. The legs of the extractor are now positioned ound the rim of the socket section of the joint and the rod clamped relative to the head, so that the screwing arrangeent may apply tension between the two sections of the joint.

In Fig. 1(*b*) a similar attachment is used to push a cone ction out of a socket, which may be on an adaptor or on e neck of a broken flask. This application is convenient hen gripping of the cone is impracticable, such as when it is aled to a Liebig condenser. As will be readily appreciated, this and in the previous example, the strip of metal used as catchpiece must be of such a length that when in the transrse position it will engage the smaller end of the cone and the same time will also pass freely through the smaller end the socket section. A series of sizes of these catchpieces is erefore necessary to fit the various diameters of joints.

The type of catchpiece shown in Fig. 1(*c*) can be applied withdraw the cone section of several sizes of conical ground int under suitable conditions. It consists of two legs nged together, each having a hooked end directed outwards shown. A spring incorporated in the hinge retains the gs in a divergent position, so that the hooks engage the lge of the cone during the extraction.

The application in Fig. 1(*d*) illustrates an attachment for extracting a cone section, the tubing of which is bent. It can also be applied on cones incorporated with ring-seals, such as the ground top of gas-washing bottles, or on the tubular type of stopper supplied to fit standard interchangeable ground sockets. This fitment utilizes a length of roller-link chain to form a clamp and the construction is described below.

A design for the extractor is illustrated in Fig. 2, being drawn in part section on planes *XY* and *ZY* to show details of the assembly. Many of the components are constructed of Duralumin alloy which has the advantage of lightness and is also sufficiently malleable to prevent it from damaging the edges of the glass joints with which it is in contact during the operation. The headpiece *A* has three slots into which the legs *B* are located with split-pins. The legs are shaped as shown in the drawing, the corners, *B*1, being used for most applications, though the corners *B*2 are necessary for the method shown in Fig. 1(*b*), where the socket is small in diameter and also has a limited flared edge. Through the centre of the head slides a threaded tubular piece *C*, which is prevented from turning by a key-way along its length into which fits a grub-screw *D*. A knurled nut *E*, threaded to fit *C*, has a grooved boss recessed into the head, which is retained by a grubscrew *F*. Thus by rotating this nut, *C* will slide through the head. A rod *G* fits through *C* and is clamped in position with a chuck *H* at the end of *C*. This chuck is made by tapering the end of *C* and slotting the tapered section lengthwise, the sections thus formed being clamped on to the rod with the knurled nut *I*. The end of the rod is slotted as shown.

The catchpieces are fitted into the slot at the end of the rod and held with a peg. This peg *J* fitting into the hole *K* is spot-welded on to a spring strip which is spot-welded on to the rod. The spring permits the peg to be withdrawn from the hole as indicated by the dotted line and thus the use of a separate pin or screw is avoided. The spring is recessed into a groove along the rod, so that the rod may be inserted through *C*.

The attachment applied in Fig. 1(*d*) is shown in detail in Fig. 3. The roller-link chain which serves as a flexible gripping band is attached to the bracket *L* by the rods *M*. The end of one of these rods is looped and fitted on to the bolt *N*, and the corresponding end *O*, of the other rod is bent as shown. The other ends of the rods are bent into U-forms over the bracket and held in the serrations *P* by the springs *Q*. The chain is wrapped once around the cone section of the glass joint, inserting some protective material between the chain and the glass. The appropriate link of the chain, required to obtain a firm grip, is fitted on to the curved end *R* of the bolt and fastened in position by tightening the wing-nut. The rods are then located in the convenient

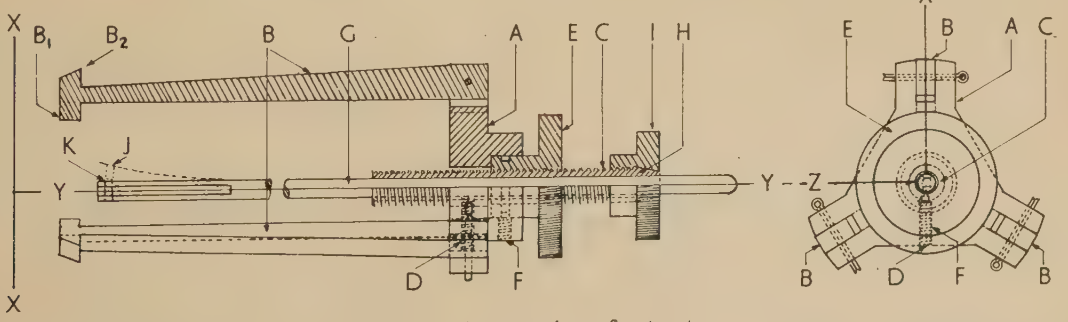


Fig. 2. Construction of extractor

serrations of the bracket, and the bent end *O* is inserted into the chain link which is diametrically opposite to the bolt. The bracket is then attached to the rod of the extractor and the joint is parted as previously explained.

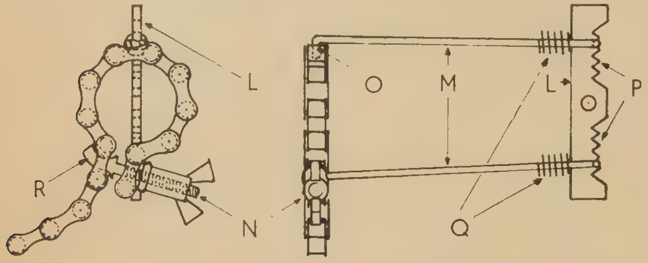


Fig. 3. Chain-clamp attachment

A joint which is so firmly jammed that it does not readily part when the extractor is applied may often be successfully parted if the joint is warmed while the force is applied.

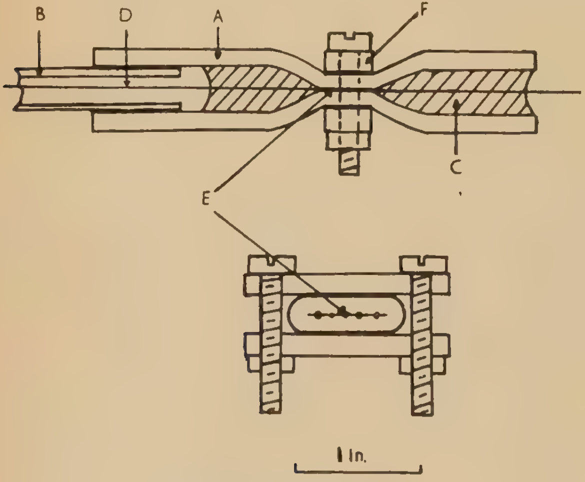
A simple demountable vacuum seal for electrical connexions

By N. Fuschillo, Ph.D., and J. Gilvey,* Department of Physics, Pennsylvania State University, U.S.A.

[*Note received* 21 *February*, 1956]

It is frequently necessary to take electrical connexions out of a vacuum system. The seal shown allows this to be accomplished with simplicity and has been used with repeated success in a number of installations.

The rubber tube *A* of thickness 0·12 in., length 3·5 in. and diameter 0·5 in. forms a vacuum grease seal with the Pyrex or metal tube *B*. The electrical connexion wires *D* are carefully separated so as not to cross and Edwards (type L) or Dow-Corning vacuum grease *C* is introduced to the extent shown. The seal *E* is formed by screwing tightly on to the rubber tube with a brass clamp *F*. An ordinary hose clamp serves quite well. The disposition of the parts of the device at the seal are shown in the lower part of the figure.



Demountable vacuum seal

The method has been used with uncovered, enamelled or glass insulated wires in systems operating at 2×10^{-6} mm of mercury. Six wires of diameters varying from 0·0
0·3 mm have been taken out of the same seal while maint
ing high insulation resistance. The system is particul
useful when used with wires which need to be continuou
cannot be safely heated, e.g. gold + 2 at. % cobalt ther
couple wires and wires of low melting point metals.
method has been used with a single 0·4 mm connexion tal
radio-frequency currents into a vacuum enclosure. In
case ease of demountability was a desirable feature. In m
laboratory applications the seal will serve as an alternativ
the more elaborate and robust designs previously describ

It is found that four inches of 0·4 mm diameter piano
can be pulled in and out of the seal repeatedly while m
taining vacuum tightness as indicated by a helium
detector. This arrangement can form the basis of conven
vacuum manipulator. By using two seals such as *E* i
likely that a simple rotary drive into a vacuum could
effected.

A micromanometer designed for recording

By G. W. E. Robertson, M.Sc., Grad.Inst.P., Londo
Research Station, Gas Council, London, S.W.6

[*Note first received* 22 *December*, 1955, *and in final for*
24 *January*, 1956]

The development of balanced and branch flues(1,2) has gi
rise to the need for the recording of very small differen
pressures, it being desirable that the apparatus be as si
as possible. Accordingly a recording U-tube manometer
been designed which is sufficiently flexible in operation
enable it to be used over a range of sensitivities in conjunct
with various types of electrical recorders.

A shielded light source is placed 10 cm from each lim
the U-tube at the level of the meniscus: the internal
external radii of the U-tube are chosen so that light pass
through the manometric liquid is brought to a focus on
sensitive surface of a photocell, as shown in Fig. 1. A pho
conductive cell incorporating a stop exposing a light sensi
area of 10 × 0·5 mm is most suitable for this purpose. Li
passing above the liquid is unfocused while a certain amo
of light is reflected downwards by total internal reflexion
the liquid meniscus.

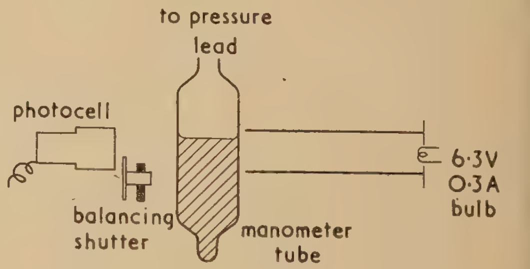


Fig. 1. General arrangement of each limb of the U-tub

The optical line image is shown in Fig. 2: the upper reg
corresponds to the divergent light: in the middle region
the light has suffered reflexion at the meniscus and in
lower region the light has been brought to a focus in
plane of the photographic paper. In practice it is advisa
to have as much of the lower light region incident on

---

[*] Now at Cornell University, Ithaca, New York, U.S.A.

[†] Smith, J. R. W. *J. Sci. Instrum.*, **29**, p. 131 (1952). Richar
C. B., and Smith, J. R. W. *J. Sci. Instrum.*, **31**, p. 431 (1954)

sitive surface of the photocell as is consistent with covering range of pressures required.

he two photocells, illuminated by light which has passed ough the manometric liquid, are placed in a Wheatstone dge circuit as shown in Fig. 3. Thus any change in the gth of the line images (Fig. 2) will bring about an increase resistance of one photocell and a corresponding decrease the resistance of the other. Now owing to the high value osen for the resistance R_4 the maximum "out of balance" rrent in R_3 will be of the order of 20 μA. Over this small nge of changes in light intensity the response of the cells n be taken as linear (see Fig. 4).

ig. 2. The optical image (negative) has been stopped own to 1 mm aperture, immediately in front of the hotographic paper so as to simulate approximately the lit incorporated in the type of photocell used. The length of the slit has been increased for clarity

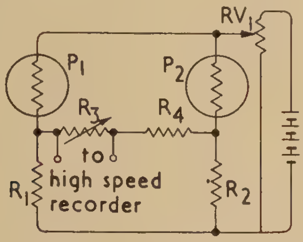


Fig. 3. Circuit diagram of two photocells in Wheatstone bridge

$R_1, R_2 = 1$ kΩ, ½%, ½ W
$R_3 = 50$–300 Ω, ½%, ½ W
$R_4 = 10$ kΩ, 10%, ½ W
$RV_1 = 0$–10 kΩ, 10%, ½ W
P_1, P_2 = Hilger FT 403

A suitable light intensity is provided by a pair of 6·3 V 3 A signal lamp bulbs placed in series so that the same current passes through each bulb. When illuminated in this manner the photocells have a resistance of about 1 to 2 kΩ; the dark resistance is, however, of the order of 10 MΩ. It is therefore important that the initial liquid level in the manometer shall be kept fairly constant; large changes in the liquid level will affect the bridge sensitivity owing to the disparity between the resistance of P_1 and P_2 on the one hand and R_1 and R_2 on the other. For this reason liquids having a low vapour pressure have been used with this manometer; butyl phthalate and butyl oxalate are most suitable, though butyl oxalate vapour is poisonous.

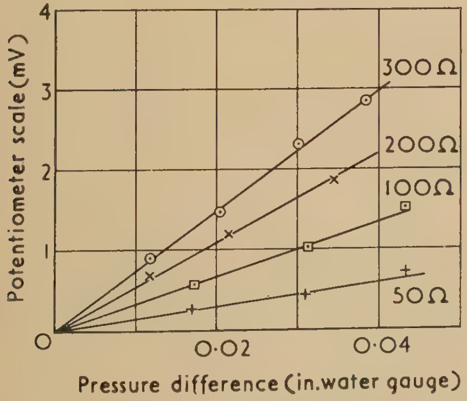


Fig. 4. Calibrations for various values of R_3 indicated on curves

The voltage applied to the two signal lamp bulbs, which serve as light sources, is somewhat less than their combined rated voltage, as it is not necessary that the bulbs should attain their maximum brightness. These bulbs are placed at the end of two 10 cm copper tubes which determine the object distance to the wall of the manometer tube. The inside wall of each tube is polished and varnished but no lenses are employed, collimation in the vertical plane being undesirable as it would diminish the height of the middle (dark) region shown in Fig. 2. Using a Pyrex tube of 1·5 mm thickness and 1·5 cm external radius, white light is brought to focus about 2 cm from the tube wall, the exact distance depending on the manometric liquid used. Immediately in front of the photocells a balancing shutter is placed and this serves as a zero adjustment; thus the amount of light reaching the lowest part of the photocells (Fig. 1) can be controlled in order to compensate for any disparity between the signal lamp bulbs. The whole optical system is enclosed in a blackened box. It has been found possible to reduce the width of the line image to ½ to 1 mm according to the liquid used and it must be remembered that surface tension effects(3) and the response time(4) will also depend on the radius of the manometric tube.

In a recording instrument of this type with no surge chamber it is important that the manometric tube be adjusted to critical damping conditions. This can be accomplished by providing an adjustable restriction in the U-tube. For moderate liquid velocities the approximation to critical damping will be sufficiently good for most purposes.

Standard methods of calibration against absolute instruments are given in the literature.(5,6) It is necessary, however, to employ a closed system having reservoirs of at least five litres volume, immersed in a water bath of large thermal capacity. Calibration of the instrument for various values of R_3 gave a series of straight line calibrations, the most sensitive having a gradient of about 0·01 in. water gauge/mV drop across R_3. These are shown in Fig. 4. When the instrument is set to its maximum sensitivity the sensitivity should not change by more than 0·0005 in. water gauge/mV.

In use it has been found necessary to clean the glass manometer tubes thoroughly every few weeks. When the tubes have been reassembled and filled to the correct level, it is necessary to ensure that the light is still focused on the sensitive area of the photocells. Re-calibration will then be necessary.

To check that the manometer has not been de-ranged, for example, owing to loss of liquid, one of the signal lamp bulbs can be shunted by a resistance of about 1000 Ω; this will give rise to a deflexion on the recorder which may be used in order to ascertain that the instrument is set approximately to the required sensitivity.

The instrument is intended for use in the ranges: 0–0·5 in. water gauge down to 0–0·05 in. water gauge; higher pressure differences may be recorded using other types of photocell.

The author wishes to thank the Gas Council and the North

Thames Gas Board for permission to publish this paper, and also Mr. G. T. Blench for his co-operation in calibrating the instrument.

REFERENCES

(1) Bennett, W. J., and Purkis, C. H. *Experiments with Common Balanced Flues.* Gas Council Research Communication GC 13 (1953).
(2) Barr, C. *Architects' J.*, **121**, p. 583 (1955).
(3) Bielak, E. B., Calderwood, G. F. N., and Marldes, E. W. J. *Nature* [*London*], **174**, p. 1010 (1954).
(4) MacMillan, F. A. *J. Sci. Instrum.*, **31**, p. 17 (1954).
(5) Ower, E. *Measurement of Air Flow*, 3rd ed., p. 233 (London: Chapman and Hall Ltd., 1949).
(6) Preston, J. H. *Engineering*, **172**, p. 645 (1951).

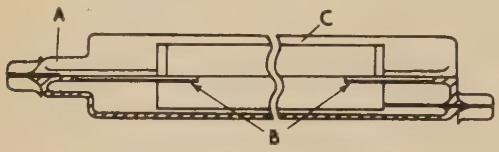
An indium foil counter for the measurement of neutron flux

By D. H. Peirson, B.Sc., F.Inst.P., Atomic Energy Research Establishment, Harwell, Berks., and F. C. Loveless, Grad.Inst.P., Twentieth Century Electronics Ltd., New Addington, Surrey

[*Note received* 21 *March*, 1956]

In the measurement of thermal neutron flux by foil activation(1) the detecting element in the form of a thin foil may be measured for β-activity by a Geiger–Müller counting tube. The sensitivity of measurement may be raised by increasing the area of foil that is irradiated and presented to the counter. However, the dimensions of the thin window of the Geiger–Müller counting tube, which is partially transparent to β-particles, is limited by consideration of mechanical strength and it is unprofitable to increase the foil area much beyond that of the counter window.

A Geiger–Müller counting tube has been designed having an indium foil of large area as cathode so that β-particles leaving the surface of the indium are registered with optimum collection geometry and without window absorption. The indium foil (0·005 in. thick) is supported by a sheet of copper gauze which is subsequently formed into a cylinder with the indium foil surface inside. This cylinder then forms the cathode *C* of the counter (see figure) and is mounted in an envelope of Osram G.E.C. type X8 soda glass. Lead glass is rejected because of the natural radioactivity of the potassium content, and boron-silicate glass because of appreciable neutron absorption.



Indium cathode counter

The low melting point of indium, coupled with the use of soda glass, presents serious constructional problems. The counter has to be so constructed as to reduce the amount of heat employed in sealing the electrodes through the glass envelope in order to avoid melting the foil. In addition, since any large-scale annealing to the glass envelope was impossible, the area of strain imposed in the sealing operation has to be as small as possible. A solution to this problem was to the anode connexion into an extension of the main enve *A*, the area of strain being considerably reduced and annealing accomplished without risk to the indium foil.

The active length of the counter is 20 cm and is define glass anode sheaths *B* which extend into the counter vo a distance greater than the radius of the cathode. procedure ensures that the active volume exists in uni field conditions. The internal diameter of the indium cat is 1·7 cm.

The counter is evacuated and carefully baked to re occluded gases, at a controlled temperature of 120° C. melting point of indium is 156° C. It is then filled pressure of 10 cm of mercury with a mixture of argon 10% of ethyl alcohol. The operating potential is 11 and the counter has a plateau of 200 V.

The theoretical performance of this counter is given b following approximate calculation. The cross-sectio thermal neutrons per atom of indium is 145×10^{-24} The cross-section per cm^2 becomes $0{\cdot}1 \times 145 \times 10^{-}$ $6 \times 10^{23}/115 = 0{\cdot}075$ cm^2 for a foil thickness of 100 mg c The cross-section for the whole cathode is $20 \times 1{\cdot}7 \times$ $0{\cdot}075 = 8{\cdot}1$ cm^2 so that the activity after irradiation t saturation value by a neutron flux of *n* neutrons. cm^{-2}. s $8{\cdot}1\,n$ disintegrations per s. The maximum energies of three groups of β-particles from indium 116 are 1·0 (51 0·87 (28%) and 0·60 MeV (21%).(2) The fraction leaving surfaces of the cathode after self-absorption is estimate be 0·4. Since only half of these will be projected into sensitive volume of the counter, i.e. the effective solid a is $2\,\pi$, the counting rate becomes $1{\cdot}62\,n$ counts per s.

For comparison, using an end-window counting (type GM4, window thickness 7 mg cm^{-2}) and an exte disk of indium, both of diameter 2·5 cm, the counting is $0{\cdot}019\,n$ counts per s.

The average background of the counting tube with indium cathode is 50 counts per min measured inside a castle of wall thickness 2 in. If necessary this figure ma reduced to about 20 counts per min by using a shield of Gei Müller counting tubes (e.g. type G24) in anti-coincidence. simple anti-coincidence circuit suitable for slow coun rates has been described elsewhere.(3) With such an arra ment the minimum neutron flux (n_0) detectable in a coun period equal, say, to the half-life of indium 116 (54 min) be calculated. As a criterion of detectability the c registered during the first half-life of decay of the satura activity is equated to three times the standard deviatio the background count in the same period. Thus

$$\tfrac{1}{2} \times 1{\cdot}62\,n_0 \times 54 \times 60 = 3 \times (20 \times 54)^{\frac{1}{2}}$$

hence $n_0 \simeq 0{\cdot}04$ neutrons. cm^{-2}. s^{-1}.

The minimum neutron flux detectable in the case of end-window counter cited above would be about 0·8 neutr cm^{-2}. s^{-1}.

REFERENCES

(1) Tittle, C. W. *Nucleonics*, **8**, p. 5 (1951); **9**, p. 60 (19
(2) Hollander, J. M., Perlman, I., and Seaborg, G. *Rev. Mod. Phys.*, **25**, p. 469 (1953).
(3) Peirson, D. H. *Atomic Energy Research Establish Report No. EL/R.* 1204 (London: H.M. Statio Office, 1953).

Correspondence

use of octal numbers for recording binary-coded information

nslating the information from a single binary scaler was er a very serious problem. Pulse height analysers using a al digital memory system[(1)] display their spectra most ply on a cathode-ray tube as a series of a hundred or so arate binary numbers each containing ten to twenty digits resented by dim or bright dots, and the problem of reading and recording this information in a reasonable time and n plotting it as a histogram is of quite a different order of gnitude. As these instruments have become commercially ilable and have come into use in a number of laboratories, eral devices have been developed to aid the decoding cess. These have ranged from slide rules and sets of tables binary to decimal conversion, to more elaborate electrical nechanical apparatus for producing either a linear analogue ıal or a digital decimal number when appropriate buttons pressed corresponding to the "one" digits of a binary nber.[(2)]

Vhile all these systems no doubt give satisfactory results, ir very diversity suggests that it is worthwhile to draw ention to a much simpler system of recording results ich has proved most convenient, in the writer's experience, working with these analysers.

This consists in the use of the scale of eight instead of the cimal scale for reading, recording and plotting the results. s found in practice that it requires very little experience to come accustomed to this scale. It has the great advantage t each three consecutive digits of a binary number respond directly to one digit of the equivalent octal mber. Thus each binary number representing the contents one channel of the analyser is read off in turn from the cilloscope screen, by immediate inspection, as an octal mber. The results are then plotted on graph paper divided o squares of 1 in. and $\frac{1}{8}$ in. It is convenient to provide a ual guide for reading off by having a scale at one side of screen to mark the position of the first digit of each group three dots. The information in a hundred channels can read off by one operator and written down or plotted by other in five to ten minutes in this way.

As an example of how the method works in practice, g. 1 shows a diagram of the screen dots corresponding to a pical group of ten channels. The table shows this information written in octal numbers, and Fig. 2 shows it plotted on $\frac{1}{8}$ in. graph paper. This is, of course, an ordinary linear plot and can therefore be translated into decimal numbers if necessary by measuring the ordinate of any point in inches, remembering that one inch is equivalent (in this example) to 1000 in the octal scale, or $8^3 = 512$ in the decimal scale. A decimal scale of ordinates can be added and if the rulings of the graph paper are then suppressed, as in preparation for publication, it is indistinguishable from a plot made using decimal numbers.

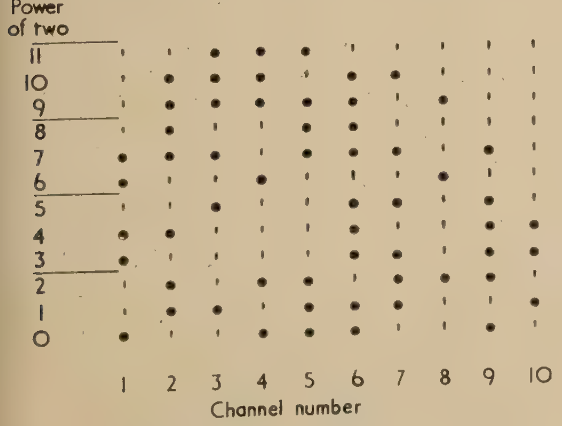


Fig. 1. Diagram of screen dots

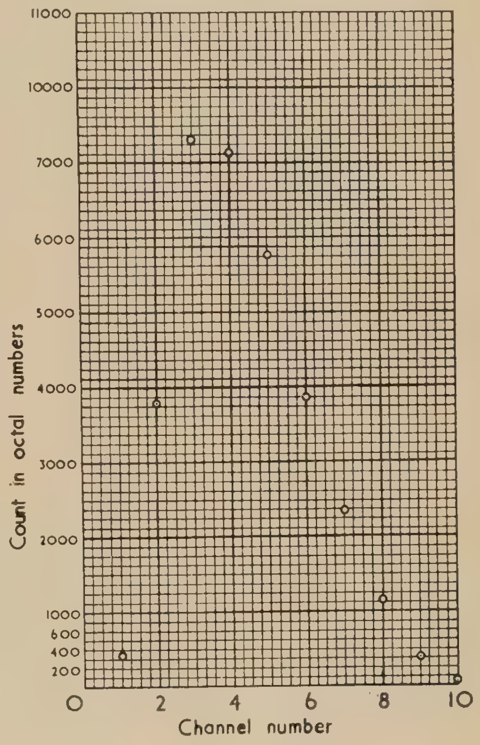


Fig. 2. Octal numbers plotted on graph paper

Channel number	*Count (in octal scale)*
1	331
2	3626
3	7242
4	7105
5	5607
6	3673
7	2256
8	1104
9	275
10	32

Background subtractions can be made on the graph by measuring the distance between spectrum and background ordinates, but it is easier, after a little practice, to make such subtractions directly with the digital octal numbers.

Areas measured under peaks on such graphs, either with a planimeter or by counting squares, give the relative intensities of lines in the spectra. This is usually the only kind of analysis that is required so that it is seldom necessary to convert the data to decimal form at any stage.

The extent of probable errors can be marked roughly on the graph with very little calculation by remembering that $\sqrt{10^{2n}} = 10^n$ on any scale, together with a very few of the smaller whole number square roots on the octal scale: $4^{\frac{1}{2}} = 2$, $11^{\frac{1}{2}} = 3$, $20^{\frac{1}{2}} = 4$ and $44^{\frac{1}{2}} = 6$. These will usually provide a sufficient range of ordinates at which the extent of the errors can be marked.

No originality is claimed for this method which has been used independently in more than one laboratory. It seems that any more elaborate but conventional system can only be justified when a kicksorter has to be used by very inexperienced operators. In this case it is probably better to make modifications to the kicksorter itself than to use auxiliary apparatus. The basic design of the kicksorter is not unreasonably complicated by making it display numbers in binary-coded decimal form, analogue linear displacements on a cathode-ray tube or even an analogue output to a pen recorder or printed-out decimal numbers.

Physics Department, University of Birmingham.

G. W. HUTCHINSON

REFERENCES

(1) HUTCHINSON, G. W., and SCARROTT, G. G. *Phil. Mag.*, **42** p. 792 (1951).
(2) SETTERWALL, M. *J. Sci. Instrum.*, **33**, p. 18 (1956).

Solarization technique for interferograms

Interferograms taken with a two-beam interference mi scope show wide fringes which rarely permit interpolatio better than one-tenth of a fringe spacing, but by emplo a special photographic technique, as described by Krug Lau,* it is possible to reduce the fringe width so that in polation to a very small fraction of a fringe spacing is possi This gives results comparable to those obtained with a mul beam interference technique with the advantage of the la magnification possible with the two-beam technique.

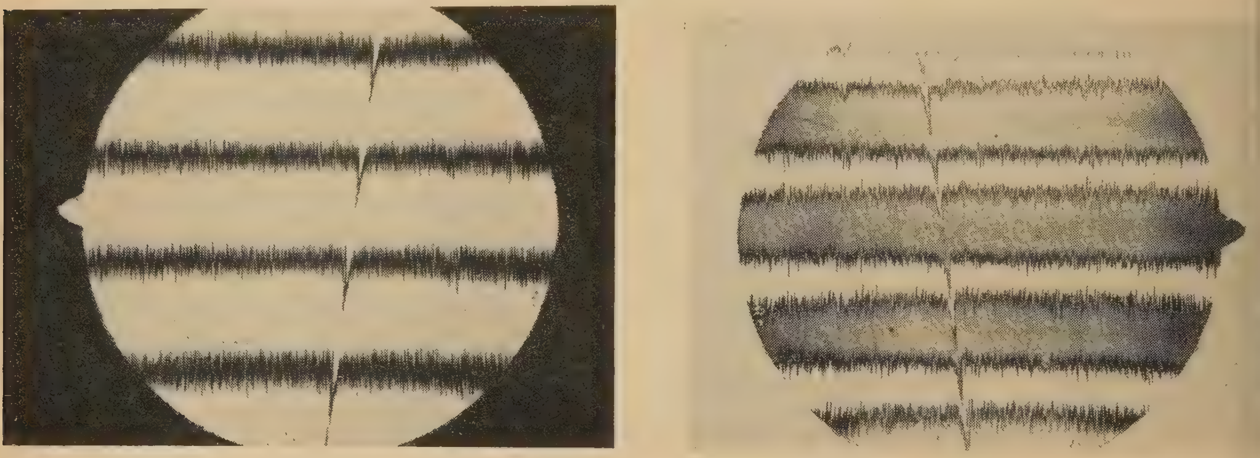
The process consists in the production of both a pos and a negative in two layers in the gelatine film on the photographic plate. The results are achieved by stop development half-way, and exposing the half developed p to a weak source of light for 2 or 3 seconds. The developn is then completed in the usual way. This interim expo causes blackening of the silver grains which were not exp in the first instance. The result is that the regions of interferogram which would have been grey in the final p now show up as fine black lines while the regions w would have been either dead black or dead white are white. The accompanying illustration shows the norm developed and solarized interferograms.

Hilger and Watts Ltd.,
Watts Division, 48 Addington Square,
London, S.E.5.

C. E. ARREGC

---

* KRUG and LAU. *Feingerätetechnik*, Heft 9 (Dec. 1952).


(*a*) (*b*)

Microinterferogram (*a*) and solarized print of interferogram (*b*) of lapped surface of slip gauge with scratch

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

ctrothermal potentiometer. H. Tinsley and Co. Ltd., Werndee Hall, South Norwood, London, S.E.25.

s instrument is intended for precision measurements and ter calibration at audio frequencies. It utilizes a vacuum rmojunction as the a.c.–d.c. transfer element. Direct rent through the thermojunction heater is adjusted by rating coarse and fine controls until a galvanometer icates zero. The circuit includes a precision resistor which duces, at a current of 10 mA, a p.d. balancing the e.m.f. ı standard cell. A continuous wire helical potentiometer is d for the fine current control to allow adjustment of current within one part in 10^5. The output e.m.f. of the thermo-ction at the standard current is balanced by an auxiliary ential circuit having coarse and fine current controls and otential slide-wire, all of which are adjusted for zero exion of the galvanometer. The direction of direct current ough the heater is reversed and the standardization and ancing procedures repeated. Owing to reversal errors, the ing of the potential slide-wire will differ from that previ-ly obtained. The slide-wire is then set to the mean of the settings, a procedure which is facilitated by the provision two scales engraved in the ratio 2 : 1, one of which can ve relative to the other. The alternating current to be ndardized is now passed through the heater of the thermo-ction and is adjusted externally (by series resistors) until galvanometer indicates balance. Since the resistance of heater circuit is adjusted to be exactly 100 Ω on a.c., the rent and voltage at balance are 10 mA and 1 V respectively, h an accuracy which is estimated to be of the order of a parts in 10^5 at 20 kc/s. External series resistors in the form precision resistance boxes are used. These are chosen to individual requirements of range and frequency.

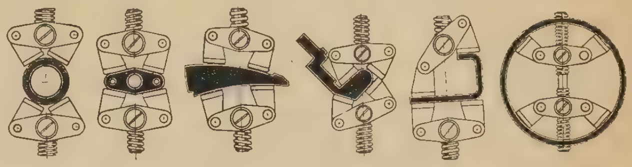
able X-band magnetrons. Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

e tunable X-band magnetron, type JPT 9-01, is intended continuous wave operation and has an integral magnet and aveguide output. The continuous wave output delivered –10 W over a 450 Mc/s band centred on 9375 Mc/s in the n band. The tuning, which is by single-knob control, a total range of 800 Mc/s including the stated 450 Mc/s ıd. A similar valve, type JPT 9-02, is intended for pulsed ration.

Tunable, continuous wave magnetron, type JPT 9-01

Machine vice. Headland Engineering Developments Ltd., 164 Westminster Bridge Road, London, S.E.1.

By employing a pivoted linkage for both jaws and jaw-carriers this machine vice can grip workpieces having an almost unlimited variety of shapes. An alternative construction is available in which both jaws and jaw-carriers can be locked in position. Some of the shapes that can be accommodated are shown in the figure. The vice is made in four sizes; the maximum extensions between jaws, when parallel, being 3, 5, 9 and 11 in.



Plan of jaws and jaw-carriers in a variety of positions

Square pulse generator. Nagard Ltd., 18 Avenue Road, Belmont, Surrey.

This instrument has been designed as a generator of fast-rising pulses and square waves, while at the same time providing a wide range of amplitude, repetition rate, width and delay, with direct-reading calibrations. The very fast rise-time of $0{\cdot}01\ \mu s$ necessitates the use of a special high-frequency connecting cable, since the output contains important frequency components of several hundred megacycles per second. This cable is supplied with the instrument, together with suitable endings. The instrument has two output circuits. The main output consists of a pulse or square wave of either polarity and of controllable amplitude calibrated to 1%. The rise-time is independent of the pulse width throughout the range $0{\cdot}2\ \mu s$ to 2 s. This signal is preceded by a pulse at the other output terminal. This pre-pulse is of either polarity, and the time interval between the two output signals is continuously variable and calibrated to cover the range $0{\cdot}2\ \mu s$ to 2 s with an accuracy of 5%. The pre-pulse and the ensuing delay period are initiated by a trigger circuit actuated either internally, by a push-button or remote contact, or by any external signal source. For internal triggering, a built-in oscillator is provided consisting of a new type of multivibrator in which the usual causes of frequency instability have been eliminated. The oscillator is continuously variable and directly calibrated to an accuracy of 5% from $0{\cdot}1$ c/s to 1 Mc/s.

Lantern slides. Epimat Slide Company, 30 Langton Road, Brixton, London, S.W.9.

Epimat lantern slides consist of a transparent sheet sandwiched between carbon paper and supported in a semi-stiff frame. They can be prepared by using either a typewriter set to "stencil" or a suitable drawing instrument. Standard sizes for British and American projection lanterns are available.

Notes and comments

British Standards Institution

The Annual Report of the British Standards Institution for the year ended 31 March, 1956, again records an increase in membership and activities. The first section of the report, which serves as a general introduction, includes references to the progress made in the study of fuel efficiency, the completion of the first British Standard concerned with smoke abatement, and preliminary steps taken in the preparation of standards required for the development of nuclear energy.

The main body of the report contains a detailed review of the standards projects completed and in hand in the Institution's four main divisions: building, chemical, engineering and textiles (and in the industries outside the scope of these four), and the work carried out under the Council for Codes of Practice.

The international section of the report contains an account of the B.S.I.'s increasing contribution to the work of the International Organization for Standardization (ISO) and the Electrotechnical Commission (I.E.C.). Among the diverse undertakings were discussions on medical gas cylinders, the revision and extension of the well-known classification of insulating materials, work on tests for chemicals, discussions on unification of screw threads, recommendations on ball and roller bearings, proposals for common names for pest control chemicals, etc.

Other aspects of international co-operation in standardization included a conference of the ABC countries (America, Britain and Canada) to secure closer unification of basic engineering standards; B.S.I.'s participation in the work of the European Productivity Agency and preparation for next year's Commonwealth Standards Conference in Delhi.

Nuclear Engineering

A new monthly periodical entitled *Nuclear Engineering* "has been designed to meet the requirements both of potential users of nuclear energy and of the manufacturers of plant and equipment." The publishers intend that it shall be of particular value to executives who need to keep abreast of these developments. Judged by this first issue this new journal under the Editorship of Mr. E. N. Shaw promises to maintain the high standard of the firm's other periodicals.

Matters which will receive attention are: power supplies and economics; public health; nuclear fuel supply; nuclear reactor fuels; nuclear reactors; chemical processing; radiation shielding; supply and treatment of special materials; heat transfer; isotopes; nuclear engineering education and training; special techniques of nuclear engineering. Regular features will include: news of contracts; industry and trade; patents; new equipment and processes; lectures and courses; movements of personnel. The first issue (published in April) measures 11¾ × 8¾ in., has 48 pages of text and 75 pages of advertisements. We wish our latest contemporary success.

The annual subscription rate is 42*s.* including postage, single copies are 3*s.* 6*d.* The publishers are The Ten Press, Bowling Green Lane, London, E.C.1.

Cambridge Instrument Co. Ltd.

Having read its twenty-eight-page brochure produced mark the occasion we are glad to felicitate the Cambri Instrument Co. Ltd. on its 75th birthday. The brochur an interesting study of how scientific instruments have bec essential industrial tools from small beginnings in university laboratories. The firm has had the advantage close co-operation with some of the leading scientists engineers of the day and in return has provided researc with instruments without which they could have achie little. We should like to call attention to a passage wh those who complain of the high price of instruments days will read with envy: "The price of instruments, theref at this stage was completely out of proportion to what sh properly have been charged." Secondly we commend following to the many designers who appear to be igno of some simple and efficient mechanical components for in instruments and must needs use complex electronic me to do a simple job, such as open and close a shutter. "Ne theless, it has always been borne in mind that 'electroni a handmaid to extend the possibilities of direct measurem and can often be employed unnecessarily and to disadva when established physical and direct electrical principles be applied adequately to a given problem." Coming a does from a firm which was pioneering electronic operated instruments nearly forty years ago, this should great weight!

Copies of the illustrated brochure may be obtained f the Cambridge Instrument Co. Ltd., 13 Grosvenor Pl London, S.W.1.

British Journal of Applied Physics

Contents of the October issue

SPECIAL ARTICLE

Neutron radiography. By J. Thewlis.

ORIGINAL CONTRIBUTIONS

Reactions occurring during decomposition of alkaline earth carbonate tungsten. By M. A. Cayless and B. N. Watts.
The dynamic magnetostriction of nickel–cobalt alloys. By C. A. Clark.
The use of the stereoscopic tilt device of the electron microscope in uni determinations. By J. A. Gard.
A possible source of error in the interpretation of electron diffraction patt By G. D. Archard.
The flow of air through beds of charcoal. By W. M. Jones.
A replica technique for particle surfaces. By J. Marriott.
Defects in germanium crystals grown from the melt. By E. Billig.
The properties of high-pressure steady-state discharges in hydrogen. By W Gambling and H. Edels.

NOTES AND NEWS

Correspondence

Large increase of light sensitivity at low temperatures for certain types of film. From K. Lonsdale and H. J. Grenville-Wells.
Arc initiation in hydrogen. From F. W. Crawford and H. Edels.

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principle construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicatio from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 6 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addres or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable i advance. Single parts, so far as available, may be purchased at 10*s.* each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute o Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

An automatic electromechanical stressing unit for creep and fatigue testing

By A. J. KENNEDY, Ph.D., A.M.I.E.E., F.Inst.P., and R. F. SLADE, B.Sc., The British Iron and Steel Research Association, London, S.W.11

[*Paper received* 13 *July*, 1956]

The apparatus is designed to apply a complex creep and fatigue stressing programme to a metal test-piece. A new electrical system has been developed which controls the extension of a mechanical spring in such a way that the test proceeds automatically under either constant stress or constant load, as required. The creep strain and the stress error are recorded during the test. The same system may be used to conduct creep recovery or stress relaxation tests.

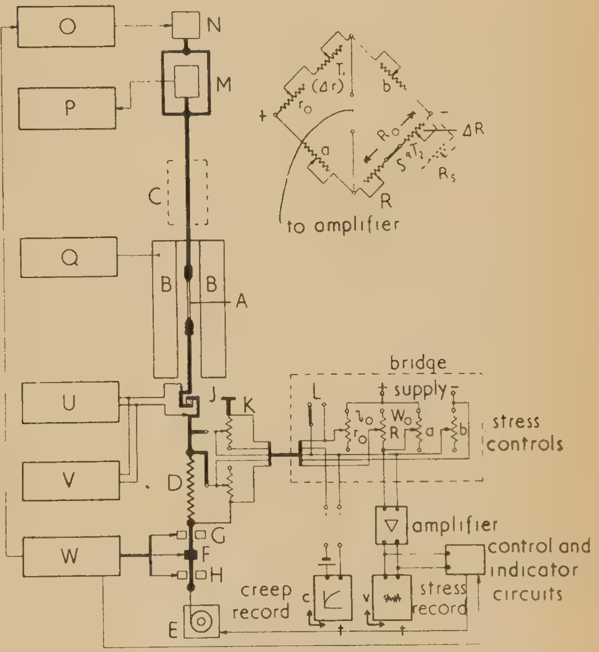
e further development of high-temperature machines such gas turbines, operating under complex stressing conditions, ends to a large extent on the production and use of special als. Simple creep or fatigue tests alone are inadequate determining the behaviour of metals under complex intertent working conditions, and special tests must be underen to determine the importance of the interaction between different processes that occur, such as creep, fatigue and overy. From a practical point of view it may be advantage- to simulate in the test the essential features of the stress l temperature conditions imposed on a particular machine nponent during working.

The present apparatus has been built in order to examine more fundamental aspects of these problems, and has n designed so that a complex stress programme may be plied and the deformation recorded. In addition, facilities incorporated for examining the stress relaxation at nstant strain, or the strain relaxation at constant stress. ch of the apparatus is quite straightforward and needs no ailed description. The new feature, which it is the main pose of this paper to report, is the electromechanical essing system, and particularly its application to creep ting. The stress is imposed by means of a mechanical ing, so that inertia effects, particularly when loading is etitive, are negligible. The extension of the spring is omatically regulated so that the test is conducted at her constant stress or constant load, the stressing being ermittent if required. A number of mechanical devices e, of course, been described in the past for achieving nstant stress by automatically varying the applied load to npensate for the changing cross-section of the test-piece ing extension. Fairly extensive references to these devices e been given in previous papers.$^{(1,2)}$

GENERAL DESCRIPTION OF THE APPARATUS

The general arrangement of the apparatus is shown ematically in the figure. The test-piece *A* is mounted in emperature-controlled enclosure *B*, its upper end being nected through a set of parallel-motion springs$^{(3)}$ *C*, to electromagnetic vibrator *N* driven by a variable-frequency illator *O*. A pick-up *M* connected in parallel with the rator enables the motion of the upper end of the test-piece be measured. A link *J* is incorporated in the rod connecting lower end of the test-piece to the creep stress spring *D*, so t a barium titanate crystal may be inserted. The signal erated by this crystal, when a vibration is applied, is measured on a calibrated c.r.o. *U*. By applying the signal to a dekatron counter *V*, the number of fatigue cycles to failure may be registered.

The creep stress is applied by driving the reversible motor *E* to pull down the lower end of the spring *D* using a high-reduction gear-box. In the absence of any special stress control facilities, the spring is extended until the stop *F* contacts *H*, when the motor is switched off. During creep, the spring *D* therefore relaxes and the resulting stressing conditions are, in fact, neither those of constant stress nor constant load. However, the system is simple and convenient, and enables an intermittent stressing programme to be imposed by driving the stop *F* between the upper and lower contacts *G* and *H* according to the time sequence set up on the programmer *W*. The deviation from constant stress is negligible as long as the creep strain is small, but for tests resulting in creep strains of 5% or more, it is more satis-



The stress controller and the general arrangement of the apparatus factory to use the stress controller. This is described in the next section.

THE STRESS CONTROLLER

The required constant stress condition (assuming the density change in the metal to be negligible) is that the product of the load applied (W) and the specimen length (l), at any instant, shall be constant. Thus if W_0 is the load imposed initially, and if the original length of the specimen is l_0, then it is required that $W_0 l_0 = Wl =$ constant. By writing $l = (l_0 + \Delta l)$ and $W = (W_0 - \Delta W)$, we may state the condition as

$$(l_0 + \Delta l)(W_0 - \Delta W) = W_0 l_0$$

where Δl is the creep strain and ΔW the corresponding reduction in load.

In the present controller, this condition is simply achieved by arranging that the resistances in the opposite arms of a Wheatstone bridge vary according to W and to l respectively, the resistances in the other arms remaining constant with a product equal to $W_0 l_0$.

The basic bridge arrangement is shown at the top of the figure. The bridge is obviously balanced when $(r_0 + \Delta r)(R_0 - \Delta R) = ab$. This condition may be compared directly with the equation displayed above. It is evident that if Δr is arranged always to be proportional to Δl, and if ΔR is proportional to the change of load ΔW, then a system which automatically maintains the bridge in balance, by resetting ΔR, is all that is required for maintaining constant stress, provided r_0 and R_0 are preset to the correct values. The actual setting-up of the device is summarized in the appendix using the numerical data for the present system.

Two resistor transducers are used for Δr and ΔR. These were manufactured by J. Langham Thompson Ltd. and can discriminate a movement of 0·001 in. over a total range of 0·5 in. The way in which these are used is shown in the main part of the figure, the bridge circuit being redrawn to show the interconnexions. The upper transducer T_1 is fixed to the main frame of the apparatus at K and the stylus, or moving contact, of this resistor is connected directly to the stressing rod. It is thus moved in accordance with the creep strain.

The second transducer, T_2, is connected across the creep spring so that the setting of the transducer is proportional to the spring extension. In order to obtain a record of the creep curve, a separate circuit is made through T_1, as shown. The out-of-balance voltage across the bridge is amplified and applied to a sign-sensitive network which drives the motor accordingly until the bridge is in balance. The quality of the system can be examined by recording the variations in the out-of-balance voltage during a test. The method offers distinct advantages over previous wholly mechanical devices in being easily adjustable for initial specimen length by setting r_0. The finite weight of the apparatus connected to the lower end of the specimen can also be accurately and readily compensated by adjustment to R_0.

Any desired intermittent stressing sequence can be applied by the programmer. When the stress is "on" the test proceeds as described above: when the stress is "off," the stop F is driven back until it contacts the limit switch G, when the motor switches off. It will be evident that a more complex stress history can be applied by varying the resistance of a or b. Any stress wave-form can be reproduced in this way. Closing the link L converts the test into one under constant load.

STRESS RELAXATION AND STRAIN RECOVER

A simple addition to the elementary bridge circuit ena the system to be used in stress relaxation or strain reco tests.

After some imposed strain, such as that brought abou creep, the internal stresses will, of course, relax with ti the external load is removed, or reduced. At the same a strain, or creep, recovery occurs. There are two stan types of test for examining this kind of behaviour, (a) recovery of strain at constant stress, and (b) the relaxati stress at constant strain. Each of these can be readily ca out with the present controller by a simple modificatio the bridge circuit.

The present device fulfils the conditions for (a) as it sta If the stress is reduced during a creep test to such a that a recovery of the strain occurs, the transducer T_1 follow this and a record will be obtained in the same wa for a creep test. In other words, the device operates constant stress system whether the strain be increasin decreasing.

In order to record (b), the stress relaxation at cons strain, use is made of a second resistor R_s in parallel T_2, as shown in the figure. If the test-piece is prestraine creep using the standard controller, as described above. by switching S so that R_s replaces T_2 in the bridge arm. test is converted to one of stress relaxation. The value is, of course, pre-adjusted to be equal to the resistance at the time the switch-over is made. The only varia the bridge circuit is now T_1, and consequently the stre controlled so that the resistance of $T_1(\Delta r)$, and hence kept constant. A record of this stress may be obtaine incorporating T_2 into a subsidiary circuit and recording current, or by recording the revolutions of the stressing m

REFERENCES

(1) Kennedy, A. J. *J. Sci. Instrum.*, **29**, p. 40 (1952).
(2) Kennedy, A. J. *J. Sci. Instrum.*, **30**, p. 371 (1953).
(3) Jones, R. V. *J. Sci. Instrum.*, **28**, p. 38 (1951).

APPENDIX

Setting-up procedure

The data for the present device is as follows:

Resistance per centimetre of motion of T_1	$6870\ \Omega =$
Resistance per centimetre of motion of T_2	$6640\ \Omega =$
The spring constant	166 g. cm^{-1} =
Finite weight of attachments	210 g =

For an initial specimen length of 10 cm, $r_0 = 10K_1 =$ 68 700 Ω

Suppose we now wish to impose a stress equivalent t initial load of 1350 g: the spring must impose a loa (1350–M)g or 1140 g, which corresponds to a known sp length. In practice, the whole device is set up with a fle but inextensible link, of the required length, in the appar in place of the spring. An adjustable stop attached to lower end of the spring is set so that the transducer T_2 is brought into circuit.

The value of R_0 is given by $(1350–M)K_2/C = 4560$ The individual values of a and b are not critical, but t are set approximately equal to r_0 and R_0 respectively. of them is then varied to obtain an exact balance. spring is now connected and the test automatically conti For a given specimen length, it will be evident that the adjustments required concern the stress. These inv resetting R_0 against a direct scale and adjusting either a or achieve a balance as indicated by a centre-zero milliamm

An electrostatic null detector

By J. Hart, B.Sc., Ph.D., A.Inst.P., and A. G. Mungall, M.A.Sc., Ph.D., P.Eng., Division of Applied Physics, National Research Council, Ottawa, Canada

[*Paper received* 11 *June*, 1956]

A simple, inexpensive and rugged electrostatic null detector for use in very high resistance bridge circuits is described. The detector has a sensitivity better than 0·5 V and has been used for potential measurements from 0 to 1000 V. It has a capacitance of about 3 pF.

frequently occurring laboratory problem is the measure- nt, to a few tenths of a volt, of the potential difference oss a very high resistance d.c. source. In this particular e the authors were interested in measuring the potential a probe in a conductivity cell containing a liquid of high istivity. The potential to be measured ranged from 0 to 0 V, and any current drawn from the probe in excess of $^{-14}$ A could be expected to disturb this potential. These ngent current and voltage requirements eliminated uum-tube electrometers from the choice of possible asuring instruments and suggested the use of some type electrostatic device. For the precision required and for absence of a large charging current a conventional multiple adrant type of electrostatic voltmeter was of little use. A ng electrometer would have been adequate, but was necessarily sensitive and delicate. It was therefore decided construct an electrostatic instrument designed to satisfy se requirements. This instrument, used in a Wheatstone dge or potentiometer, was accurate to about 0·5 V, with gligible current flow from the source.

CONSTRUCTION

The instrument, Fig. 1, could be made quickly at low cost l is simple and sturdy; it has two fixed plates, *A* and *B*, l one movable plate, *C*. The movable plate is a thin sheet brass with narrow extensions at the top and bottom: the flexible extension is soldered to a terminal at the top of erspex enclosing box and the two side plates are connected dly to terminals on the sides of the box. The central vable plate hangs evenly spaced between the two outside tes and its bottom extension lies midway between the two posing Perspex knife edges, which act as stops. The pension was observed through a simple lens; a more porate optical system would give a higher precision but uld also eliminate many of the advantages due to the plicity of the instrument.

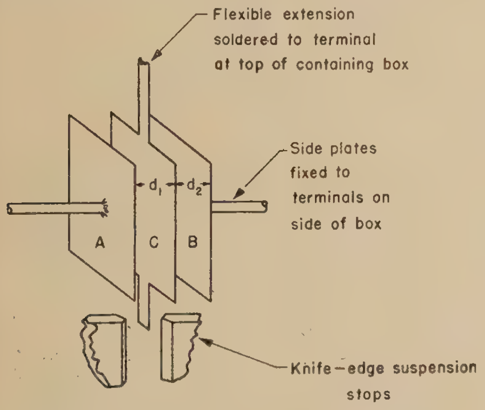

Flexible extension soldered to terminal at top of containing box
Side plates fixed to terminals on side of box
d_1
d_2
A
C
B
Knife-edge suspension stops

Fig. 1. The electrostatic null detector

The capacitance of the detector is less than 3 pF, the sensitivity less than 0·5 V and the resistance in excess of 10^{15} or 10^{16} Ω. The steady current drawn from the probe and the charging current can thus be made several orders of magnitude less than if an electrometer triode circuit or a multiple plate quadrant electrostatic voltmeter were used. The time constant is governed by the mechanical response, and is of the order of 1/50 s.

PRINCIPLE OF OPERATION

The detector operates in the following manner. If a voltage is applied between plates *A* and *B*, and plate *C* is maintained at a potential V_1 with respect to *A*, and V_2 with respect to *B*, then, from well-known principles of electrostatics, plate *C* experiences a lateral force toward plate *A* approximately given by

$$F = \frac{A}{2}\left(\frac{V_1^2}{d_1^2} - \frac{V_2^2}{d_2^2}\right)$$

where d_1 and d_2 are the separations shown in Fig. 1. Edge effects are neglected. In the absence of suitable mechanical restoring forces, plate *C* is in unstable equilibrium, and will move either toward plate *A* or *B*, depending on which term inside the brackets dominates. In practice, a stable situation is possible, however, if a suitable mechanical restoring force is superimposed; in the instrument built this is provided by the flexible extension at the top of plate *C*, Fig. 1. From the equation, it appears that the higher the voltage, the larger the plate area, and the smaller the separation the higher the sensitivity. With increasing sensitivity, the limits of stable motion narrow, and the knife edges must be placed progressively closer together. For practical purposes there is then a limit to the increase of sensitivity by these means.

In one instrument built by the authors, d_1 and d_2 were approximately 1 mm, V_1 and V_2 150 V, and the separation of the knife edges 0·5 mm. All three plates were 1·5 cm by 1·0 cm in area. The central plate with its extensions was

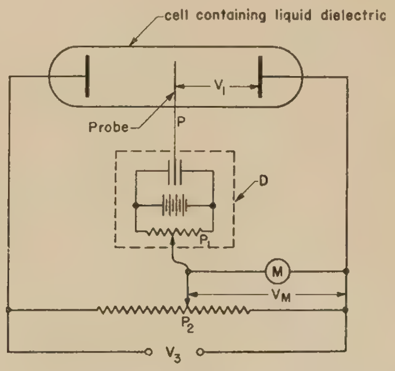


Fig. 2. Measurement of potential with the electrostatic null detector

cut from brass sheet 0·025 mm thick, the top extension being about 8 mm long and 1·5 mm wide, and the bottom one 5 by 2 mm. The construction was completed in a few hours.

Before potentials can be measured by the instrument the following procedure is necessary. Without any voltages applied, the moving plate is approximately centred between the two outside plates and the lower extension of it centred between the knife-edge suspension stops. Then the suspension terminal is connected, Fig. 2, to the moving point of a potentiometer P_1, a battery is applied across the outside plates and P_1 is adjusted so that the suspension returns to the original central position between the knife edges. This adjustment is necessary since the suspension cannot be mechanically centred sufficiently precisely between the plates for equilibrium in the absence of electrical forces. Then, when the field is applied, the voltage on the central plate must be adjusted so that the mechanical equilibrium is not disturbed. In practice, this adjustment is small.

MEASUREMENT OF POTENTIALS

Potential measurements are made in the following w In Fig. 2, the section enclosed in the dotted line is the detector D: the rest of the figure shows the high resista cell across which is placed a large voltage V_3, and a poten meter P_2 which draws enough current for a conventio voltmeter M to be used to measure the voltage V_M. Vol V_1 is the potential which is to be determined at the prob The moving point of potentiometer P_2 is adjusted until detector D indicates a null. Then V_M, the voltage read M, is identical with V_1, the voltage to be determined. perfect balance, no current is drawn from the probe P actual balance conditions dictated by the sensitivity of null detector, the current drawn depends on the resista and capacitance of the detector and the unbalance vol $V_1 - V_M$. Norman* gives full details of the circuits nee for measurements with guarded electrodes.

---

* NORMAN, R. H. *J. Sci. Instrum*, **27**, p. 200 (1950).

An electrical indicator for a mercury U-tube manometer

By A. E. HAWKINS, B.Sc., A.R.C.S., A.Inst.P., Department of Physiology, Royal Veterinary College, University of London

[*Paper first received* 21 *March, and in final form* 4 *June*, 1956]

The metal limbs of a U-tube act as outer conductors of two cylindrical capacitors. The tubes are coated internally with a thin layer of a dielectric material. The mercury acts as a variable inner conductor. The system can be made very sensitive and has a general scatter of less than ±1 mm of mercury.

A Siemens high-speed, double changeover relay can be used in Thomson's method of mixtures to give a very sensitive null method for the comparison of capacitance. The circuit has been utilized in the construction of a simple mercury manometer of very high sensitivity which gives a continuous indication of pressure difference.

PRINCIPLE OF THE APPARATUS

Each limb of the U-tube consists of a metal tube coated on the inside with a thin layer of a dielectric material. The limbs are joined at the bottom by a tube of insulating material, with a short length of metal tubing somewhere in its length to enable electrical contact to be made with the mercury. The mercury acts as a variable inner conductor of the two cylindrical capacitors, and the metal tubes forming the limbs act as the outer conductors. A pressure difference across the U-tube produces an increase in capacitance of one limb and a decrease in capacitance of the other. The U-tube is used with Thomson's circuit rather than with an alternating current bridge, as a null indication is obtained by adjusting only one component. The arrangement gives an out-of-balance direct current proportional to the change in capacitance after balancing. In this manometer, the change in capacitance is a direct measure of the change in pressure difference.

DETAILS OF THE APPARATUS

The U-tube and the associated circuit are shown in Fig. 1. Various materials were used as the dielectric; the most successful was found to be the commercial lacquer Vals This lacquer covered bare metal very well with a single, t coat. Brass tubes were thoroughly cleaned with fine em paper wound on a rod, the rod being rotated within tubes by an electric drill or on a lathe. In order to c the tubes, they were filled with lacquer and then allo to drain in a vertical position. When dry the tubes w inverted for use in the manometer. Only once did a si layer of lacquer fail to cover the surface in a satisfact manner.

When a layer of uniform thickness was required in a tu the tube was rotated for an hour at approximately 750 rev/m The rotation was in a horizontal plane about the longitudi axis of the tube and was commenced as soon as lacq ceased to drip from the tube when in the vert position.

The junction tube was of rubber in all cases. It was fou initially that the dielectric material was sometimes remo accidentally when attaching the rubber tube and someti it did not cover the bottom edges of the tubes properly. T was overcome by allowing the lacquer to dry, dipping tubes into smoking beeswax-and-resin, allowing the wax harden, and inserting an inner rubber sleeve before the rub junction tube was attached.

Supporting the tubes presented no difficulty. They w bolted to a board using strips of ebonite, or were held Terry clips. Wide tubes, carrying a large volume of merc were held with clamps with rubber covered jaws, and, safety, the junction tube was tied and waxed on to manometer tubes.

METHODS OF USING THE APPARATUS

There are several ways of using the manometer, but the o described below are considered to be the most satisctory and generally useful. For both of them the resistance is kept constant and the value of a decade resistance box is varied until balance is obtained. As, at balance, $/C_2 = R_2/R_1$ it is evident that a linear relationship does t exist between pressure difference and the value of R_2.

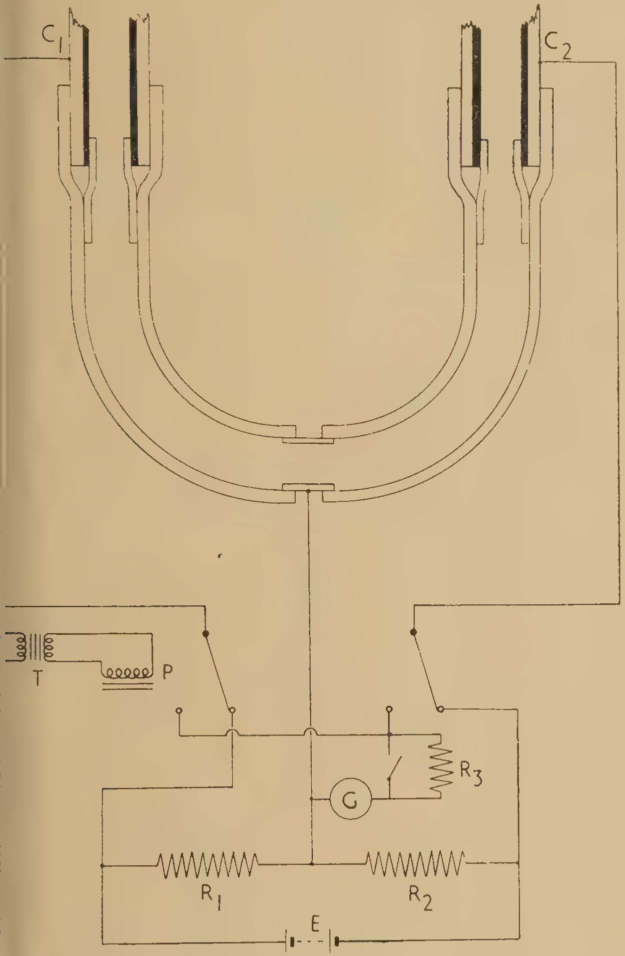


Fig. 1. Circuit diagram of manometer

$T = 6{\cdot}3$ V filament transformer; $P =$ Siemens type 100 high-speed, double changeover relay, 53 Ω; $R_1 = 10$ kΩ; $R_2 =$ 100 kΩ decade box; $R_3 = 1$ MΩ; $E = 120$ V dry battery; $G =$ Tinsley portable reflecting galvanometer, type SS1, 22 mm/μA, 320 Ω.

If the dielectric layer is uniform throughout the length of he tubes, the same deflexion is obtained for the same change f pressure difference from a balance point anywhere in the ange of the manometer, since the out-of-balance current is roportional to CV, where C is the capacitance change on ach side and V is the voltage applied to the bridge.

If a linear relation between pressure difference and the alue of R_2 is essential it can be obtained with a reduced ensitivity for the same value of electromotive force. One mb is disconnected and replaced by a fixed capacitor of the ame order of capacitance. Then, provided the dielectric yer is uniform, there is a linear relation between pressure ifference and the value of R_2.

PERFORMANCE OF THE APPARATUS

For experimental work on this apparatus two sets of tubes were used. These had internal diameters of 1·02 and 2·51 cm, respectively.

With the draining technique described, it was not expected that the layers would be uniform over their entire length. Using the circuit described, the capacitance (i.e. the apparent capacitance) of the tubes with various heights of mercury was measured and the non-uniformity confirmed. It was generally constant, however, over 10 cm lengths. The spinning of tubes up to 50 cm in length produced layers which were uniform except for 5 cm at each end.

The sensitivity of the apparatus depends on the internal radius of the tubes, the thickness of the dielectric layer, the inclination of the tubes, the sensitivity of the galvanometer and the electromotive force used. The galvanometer had a sensitivity of 22 mm/μA and, except in one case, the electromotive force was kept at 45 V. A very sensitive galvanometer (2300 mm/μA) did not improve the performance of the circuit to any great extent since, with its longer period, it began to oscillate owing to occasional transient currents, for example, when the tongues of the relay did not close together exactly. This made the determination of the balance point difficult and partially nullified the increased sensitivity.

A carbon tetrachloride manometer was originally used for calibration purposes, but this had to be replaced by a water manometer when very cold weather prevented adequate ventilation being used to remove the vapour.

Most of the exploratory work was carried out using both limbs of the U-tube as it was felt that the differential effect would partially eliminate errors due to meniscus shape. This was found to be so except when the pressure difference was changing slowly. For slow changes of pressure difference it was therefore necessary to calibrate the manometer by

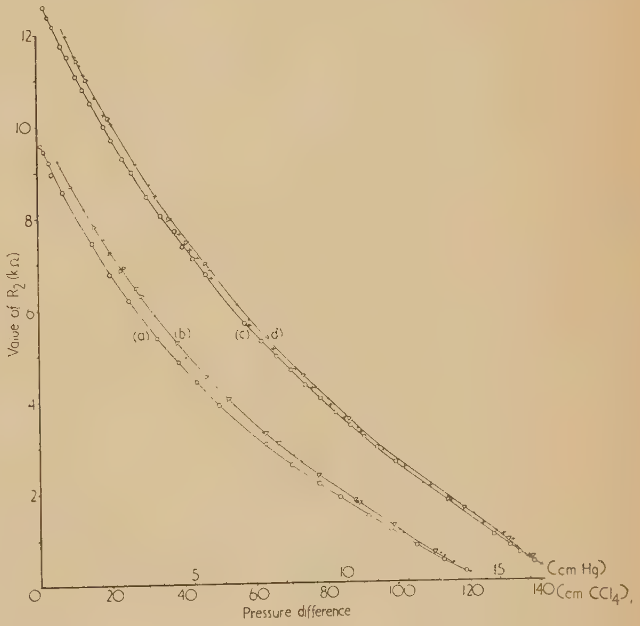


Fig. 2. Values of R_2 plotted against pressure difference. Narrow tubes

Curves (*a*) and (*b*) are for V-manometer; curves (*c*) and (*d*) are for U-manometer.

△ calibration; ● random; ○ slow fall of pressure difference; × slow rise of pressure difference.

changing the pressure difference slowly. This is shown in curves (*a*) and (*b*) of Fig. 2. The curves were obtained with the narrow tubes with two coats of lacquer. The tubes were inclined to each other at 120°. The manometer was calibrated by setting up a particular pressure difference and then allowing the columns to settle after being caused to oscillate by squeezing the tube connecting the two manometers. The performance was then checked by setting up pressure differences at random, and without squeezing the connecting tube. The results were found to be very satisfactory, as may be seen in curve (*b*). However, when the pressure difference was allowed to fall slowly (10 cm of mercury/hour) curve (*a*) was obtained. A similar effect was observed when the pressure difference was slowly increased. As may be seen in curves (*c*) and (*d*) of Fig. 2, the effect was not so marked when the limbs were vertical.

Provided the calibration has been carried out under the appropriate conditions the apparatus can be used to measure slow changes of pressure very conveniently and in considerable detail. This is demonstrated in Fig. 3 where part of three long runs with a constant leak are shown. The change in pressure difference with time was determined with a water manometer and then the original pressure difference restored. The leak was re-opened and the resistance readings with time taken. The equivalent pressure differences were obtained from a normal calibration curve and finally the galvanometer deflexions with time were taken. The rapidity with which pressure readings can be taken is clearly shown. The superiority of resistance readings over galvanometer deflexions is also evident.

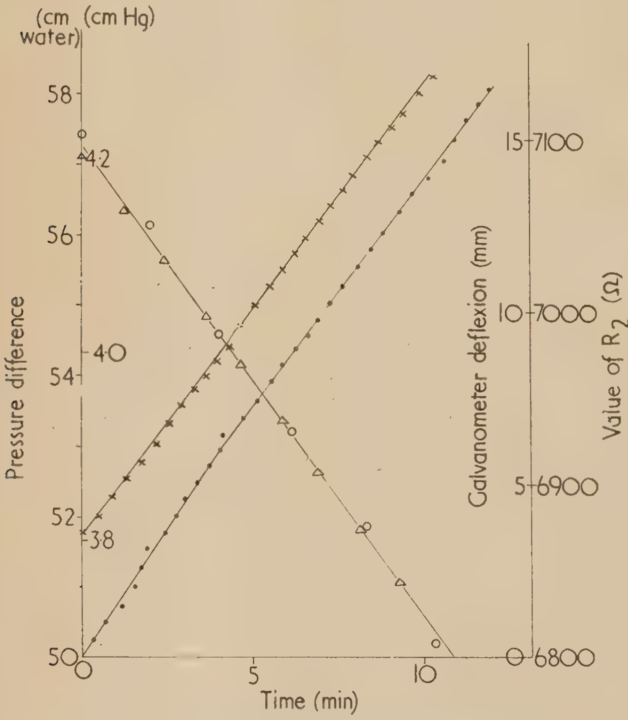


Fig. 3. The measurement of a slow change of pressure difference

○ water manometer; ● galvanometer deflexion from balance; × values of resistance R_2; △ water manometer values derived from values of R_2 by calibration curve.

It has been mentioned that theoretically the deflexions f zero are proportional to the change of pressure differe This was confirmed with both sets of tubes and with s and double layers of Valspar. It was found that the us a single calibration line could involve an error up to a ±1 mm of mercury, but that individual calibrations w give a lower indeterminacy of the order of ±0·2 mm mercury. The scatter was approximately the same for t with uniform and non-uniform layers. It appears to be to meniscus effects.

The sensitivity of the apparatus to change of pres difference can be made very high. With the narrow tu a single layer of Valspar, an electromotive force of 1 and the tubes inclined to one another at 120°, a chang pressure difference of less than 0·1 mm of mercury car detected. As this sensitivity is masked by the meniscus er it is of no use when measurements of pressure difference being made, but it could be of use as a detector of mi pressure changes.

The sensitivity to change remains the same whatever initial pressure difference may be. It is this feature of apparatus which renders it different from any other typ sensitive manometer working over the same wide range pressure difference.

The sensitivity increased by approximately the exp amount on sloping the narrow tubes, whilst the maxim scatter remained substantially the same at ±1 mm of merc near zero pressure difference and ±0·7 mm of mercury c the rest of the range, where it remained fairly constant. sensitivity increased when the diameter of the tubes increased, but the maximum scatter rose to ±1·5 mm mercury and ±1 mm of mercury. The sensitivities obtai are given in the table.

Indicator sensitivities

Tube size	*Coats of lacquer*	*Arrangement*	*Sensitivity*
Small	1	U	2·7
Small	1	V	4·6
Small	2	U	2·1
Small	2	V	3·6
Large	1	U	3·5

Sensitivities in mm deflexion of galvanometer per mm mercury change of pressure difference. Galvanome sensitivity = 22 mm/μA, battery e.m.f. = 45 V. V = tu inclined to each other at 120°.

CONCLUSION

It has been shown that the system is satisfactory mercury. It was not found possible to produce a satisfact water manometer using an electrolyte in the water to act the variable conductor. Dielectric breakdown was fina overcome but there remained the difficulty that over thi seconds was required for the conducting fluid to become f from the dielectric when a column was falling.

ACKNOWLEDGEMENTS

The author wishes to thank Prof. E. C. Amoroso for interest and encouragement in this work and Miss Tomlinson for technical assistance.

Eight-channel recording on ¼ in. magnetic tape with a stationary-tape playback

By J. C. Barton, Ph.D., University College of the West Indies, Jamaica, B.W.I.

[*Paper first received* 15 *December*, 1955, *and in final form* 7 *February*, 1956]

A method of constructing multi-channel magnetic heads is described and their performance reported. The problem of interference between channels is discussed and details given of a new technique for reducing this interference. The playback equipment consists of an eight-channel head mounted on an electrically maintained tuning fork so that it picks up signals from a stationary tape. Signals from each channel are switched electrically in time succession and, after amplification, displayed simultaneously on an oscilloscope. It is possible to resolve pulses recorded along the tape at a separation of 0·1 mm. Precautions necessary for observing very small signals are discussed.

the development of a portable cosmic-ray hodoscope it s necessary to record eight channels of information, nveyed by the presence or absence of electrical pulses, in minimum possible space. The cosmic-ray apparatus has en described in a previous paper,(1) while the special tech-ques of magnetic-tape recording, which may be of more neral use, are presented here.

Most multi-track magnetic-tape systems record only two four tracks simultaneously on the standard ¼ in. magnetic pe, although it is known that the tape tracks themselves n be very narrow. It has been found that attempting to cord eight channels simultaneously on the same size tape akes the construction of the magnetic heads more difficult d greatly increases the electrical interference between jacent channels. The way in which these problems have en solved is described in the earlier part of this paper.

A further difficulty arises in analysing the records as it is cessary to decide how many of the recording channels ere energized simultaneously. The separation of pulses ong the tape may be only a few thousandths of an inch d it is clear that the conventional type of magnetic tape ayback is quite unsuitable for this analysis. It is obviously uch easier to examine the records if one uses a method of ayback in which the tape is kept stationary. Several ethods have already been proposed in which it is the agnetic induction of the tape, rather than its rate of change, hich is detected. These include a refinement of the iron ings technique for exploring magnetic fields, the deflexion an electron beam as was used by Skellett and others,(2) d the various fluxgate methods, which have been discussed Daniel.(3) None of these methods appear suitable for ulti-channel use with small signals, at least for the very arrow tracks which are used in this work. A more pro-ising approach is that of Sorrells(4) in which a magnetic ead is rapidly rotated and made to scan a short section of e tape. Its disadvantages are the high degree of mechanical recision which is necessary and the use of slip-rings with gnals of very small amplitude.

The method described in the later part of this paper, hich has been developed independently of the above one, oids its disadvantages. It consists essentially of a multi-annel head fixed on one of the tines of an electrically aintained tuning fork. The amplitude of oscillation can quite moderate, which is useful in confining attention to a nall section of the tape, but the relative velocity very high. hus for a peak-to-peak amplitude of 1/16 in. and a frequency 160 c/s the maximum velocity is 63 in./s. This greatly mplifies the problems of interference from noise and hum. was found convenient to arrange that each channel was electrically switched in time sequence and the signals combined on a single oscilloscope display.

CONSTRUCTION OF MAGNETIC HEADS

The only suitable mu-metal laminations which could be obtained fully annealed were type 803 by Magnetic and Electrical Alloys Ltd., and these have provided the basis for all the work described. The thickness of these laminations is 0·015 in. so it is only possible to use a magnetic circuit one lamination thick for each track. The individual heads then consist of two of these laminations. The process by which the laminations are stamped out of sheet rounds off the edges of one side of the lamination and it is therefore important always to use them with all their more rounded edges on the same side. The centre section of each lamination is first insulated with two turns of 0·0005 in. polystyrene tape and then wound with 70 turns of 44 s.w.g. synthetic enamelled copper wire; the lead-out wires are secured with polystyrene tape.

Considerable care is necessary in the assembly of the head, especially to avoid breaking off one of the lead-out wires. The method adopted is to assemble the laminations in two stacks of eight, each of which will be half the complete head (Fig. 1). The spacing between the laminations is maintained by strips of brass shim, 0·015 in. thick. The clamps in which the laminations and spacers are assembled are also made of brass; these have to be made very accurately if the final line-up is to be correct.

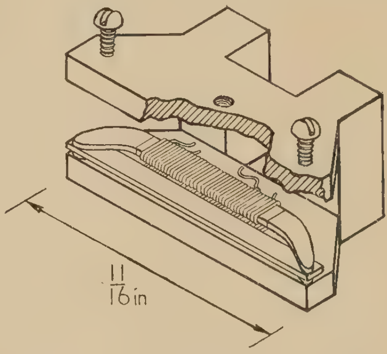


Fig. 1. One stack of laminations

The face of each stack is ground down until the tips of the laminations are exposed over a length of a millimetre and the assembly of laminations and spacers is exactly plane.

This operation is very tedious, but the uniformity of the final heads depends very largely on the care with which it is carried out. The two halves can then be brought together with a piece of 0·0005 in. mica between them to provide the gap spacing. They are secured with two steel links at the top and bottom of the clamps (Fig. 2). A gap has been provided at both front and back with the idea that the latter might reduce the effects of residual magnetism; it is not known if this is essential. The front of the head is ground to a suitable contour and polished in the usual way. The final stages in construction are to connect the two halves of each individual head, earth one end of each head and take the other ends to a sub-miniature tag board mounted on the back of the head. An aluminium mask is fitted over the head to keep the tape accurately alined.

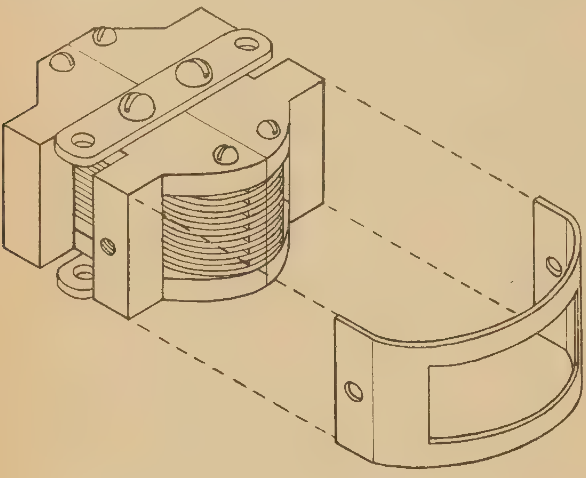


Fig. 2. Complete magnetic head

MAGNETIC HEAD PERFORMANCE

The characteristics of recording heads can only be considered in conjunction with the particular tape used. Various grades of tape have been tried to see which would give satisfactory recordings with the least current. The results obtained using low coercivity tape were always disappointing, probably due partly to a higher noise level and partly to the greater self-demagnetizing effect, which will be very large for a short recorded pulse.(5) Of the various medium coercivity tapes which have been tried the most successful has been Emitape No. 88, made by Electric and Musical Industries Ltd. (The response of a tape to pulses does not necessarily correlate with its response to a correctly biased signal on a normal tape recording machine.) Due to the non-linear form of the curve relating remanent flux to magnetizing field the current required to give an adequate signal-to-noise ratio on playback is defined rather sharply. The magnitude of this current also depends on the characteristics of the playback arrangement, but not very critically. Using the same type of head for both recording and playback the minimum recording current needed on any channel is between 12 and 15 mA. For recording pulses it is possible to use a steady magnetic bias and thus reduce the pulse current required. In practice it was found that this increased the noise level of the tape so that the additional complication did not seem to be justified.

The resistance of each channel is 3·2 Ω and the self-inductance 0·62 mH so that the heads are usually operated in conjunction with impedance-matching transformers. magnetic energy, which has to be supplied by the sc within the duration of the driving pulse, is $\frac{1}{2} Li^2 = 0{\cdot}70$ and the rate of energy dissipation is $Ri^2 = 7200$ ergs/s follows that for pulse lengths much greater than 0·70/ = 100 μs the reactive component of the head impedan unimportant. On the other hand for shorter pulse len the power available for the duration of the pulse must incr inversely with the length of the pulse. Since the brass s were not insulated from the laminations, eddy current ef might become appreciable when using very short pu their effects were not apparent with 100 μs pulses.

INTERFERENCE BETWEEN CHANNELS

With the multi-channel head described above, the in ference between adjacent channels is so large that if sig are recorded simultaneously on, say, channels two and the spurious record on channel three may be comparab magnitude to a true signal. Several possible causes o effect have been examined:

(1) Any difference in spacing between the channels the record and playback heads will obviously lead to of true signals and greater apparent interference.

(2) The tape alinement must be accurately maintained.

(3) There is some spread of the recorded region on tape due to fringing effects at the gaps.

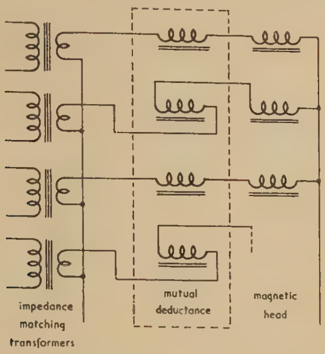
(4) There is capacitative and mutual inductive coup between the heads.

It has been found that, provided the head is made sufficient care, the interference is due mainly to the mu inductance between adjacent heads, which is about 0·11 One possible way to overcome the problem is to stagger individual heads along the length of the tape. This solut was rejected because it would take up more space and wo cause great difficulties in the alinement. Another solut would be to insert a magnetic screen between each pair heads but this would require thinner laminations and m the construction extremely difficult.

It has therefore been necessary to develop a new meth of eliminating the interference.(6) The principle of t method is to introduce deliberately a mutual inducta between adjacent channels which is opposite in sense that at the head. One way of doing this, which would better than using seven double-wound transformers, is use a second eight-channel head, identical with the fi which is connected in series with the recording head with alternate channels reversed in sense. It can be se however, that this is not the best arrangement since half available power must be wasted in the second head. It better to use a device in which the ratio of mutual to se inductance is as high as possible.

A device of this type, which may be called a mutual dedu ance, consists of eight of the same laminations as are us for the head, but each wound with 90 turns of 44 s.w wire. These are placed as closely together as possible, be held in a small block of Tufnol. In this way we can obtai mutual-inductance of 0·10 mH for a self-inductance 0·36 mH. Rather higher values would be preferable, there is no space available for a greater number of tur Connexion is made to the head in the manner describ above and shown in Fig. 3.

Using pulses with a sharp rise and an exponential decay 100 μs time constant it has been found that the device unde compensates, possibly through spread of the recorded regi the tape. We have therefore used one unit on the rding equipment and two units, connected in series, for playback. The compensation finally achieved is still perfect, which is not surprising in view of the variation ween channels. By using the deductances the spurious



ig. 3. Circuit diagram for multi-channel recording

als can be reduced to not more than 20%, in the worst e, of a true signal and this has proved adequate in practice. out one-third of the available recording power is dissied in the deductance, but this is no more than would be t into adjacent channels without it. Interference between -adjacent channels is never important.

PLAYBACK: TUNING FORK AND TAPE DRIVE

The tape transport mechanism and the tuning fork are unted on a vertical wooden board in the manner shown Fig. 4. The fork used is an ordinary 256 c/s one which, en loaded with the magnetic head and counterweight, onates at about 160 c/s. A lower-frequency fork would uce the head velocity while a higher-frequency fork was nd to be very difficult to excite when loaded.

The electrical leads from the magnetic head are brought ng the tine of the fork to its base. It was discovered that it was very important to secure these leads throughout their lengths since, if free to vibrate independently, they picked up large spurious signals from the stray magnetic fields. Rather surprisingly, it has not been found necessary to magnetically screen the head itself. The exciting electromagnet is placed adjacent to the opposite tine of the fork and this may have helped to reduce any interaction.

The magnetic tape drive is arranged so that the tape can be advanced without altering its tension, which must be adjusted so that there is good contact between the tape and head but without damping the oscillations of the fork too heavily. The tape is usually advanced so slowly that it has not proved troublesome to wind on the take-up spool by hand.

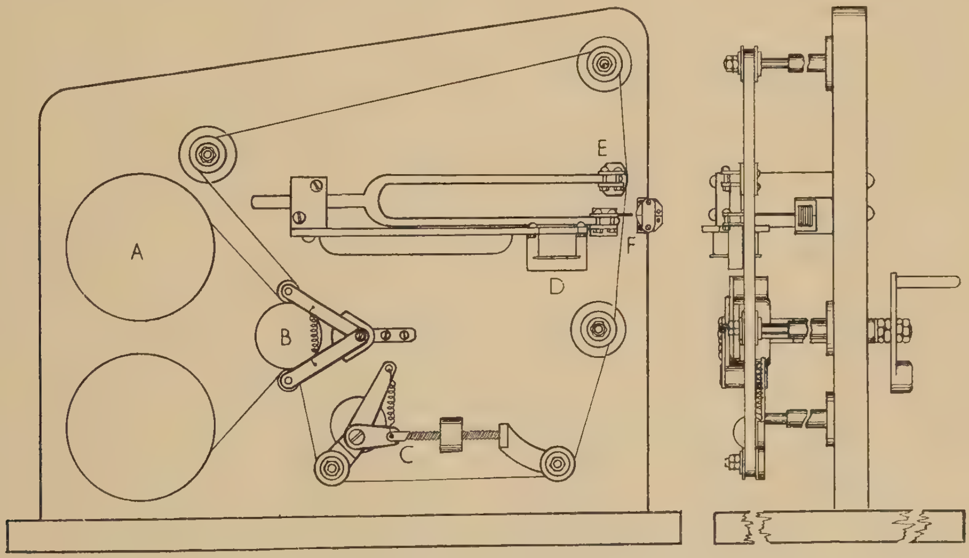


Fig. 4. Tuning fork and tape drive

A, take-up spool; *B*, tape drive mechanism; *C*, tension adjusting device; *D*, exciting electromagnet; *E*, eight-way magnetic head; *F*, synchronizing pick-up coil and magnetic finger.

PLAYBACK CIRCUITS

Once it has been decided that the eight channels should be combined in time sequence by electronic switching it is obviously preferable to combine the signals before they have been amplified, as the need for a multiplicity of high-gain amplifiers is then avoided. The only disadvantage is that it then becomes necessary to take special steps to remove the large "pedestals" which are inevitable when gating signals of small amplitude. The operation of the circuits can be followed on Fig. 5. The channels are switched on in turn, for each successive single sweep of the head, by using an Ericsson 12-way selector tube in which the discharge is advanced twice for each cycle of the fork.

The fork is excited by an unpolarized electromagnet and therefore requires a frequency of only 80 c/s. The alternating voltage has to be locked in phase with the voltage which is used for switching from one channel to the next; this is achieved by using the same selector tube as a frequency divider. After the signals have been combined they are amplified and passed through the second gating circuit to remove the pedestals. The selector tube has a third function in that it triggers the time-base display circuits of the cathode-ray oscilloscope.

The circuits are assembled in two separate units. The gated pre-amplifiers and two-stage amplifier comprise the first unit, of size 8 × 5 × 3 in, while all the remaining circuits comprise the second, of size 16 × 8 × 5 in. The former uses only battery-operated valves, which has proved a convenient method of avoiding any trouble from mains hum. The details of the circuits are shown in Figs. 6 and 7 and only a few special features of them need to be described.

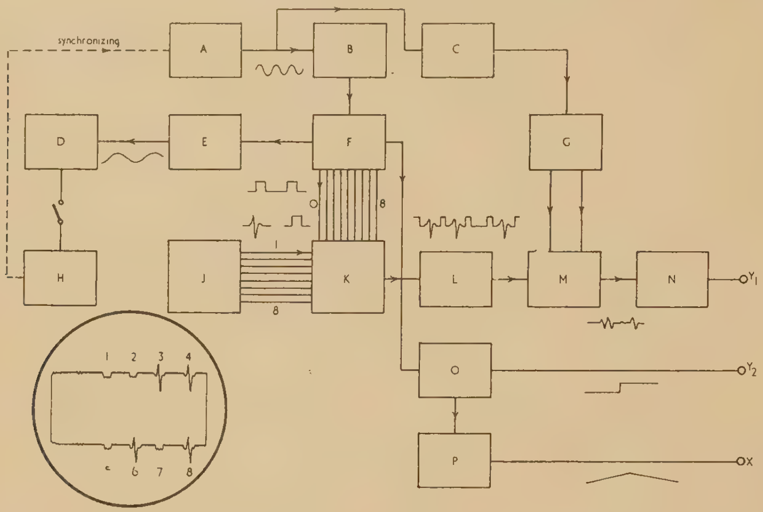


Fig. 5. Block diagram of circuits

A, master oscillator, 320 c/s;
B, buffer amplifier;
C, phase splitter;
D, power amplifier;
E, selective amplifier, 80 c/s;
F, twelve-way selector tube;
G, push-pull amplifier;
H, tuning fork, 160 c/s;
J, eight-way head;
K, eight-channel gated pre-amplifier;
L, two-stage amplifier;
M, four-diode gate;
N, final signal amplifier;
O, bi-stable trigger circuit, $26\frac{2}{3}$ c/s;
P, integrating circuit.

The gating of the various channels is carried out by applying the voltages from the output cathodes of the selector tube directly to the screen grids of V_1–V_8. These are not the most suitable valves but were the only sub-miniature ones readily available. The top portions of the voltage pulses from the selector tubes have an irregular shape so the crystal diodes are included to limit them. The large pedestal effect

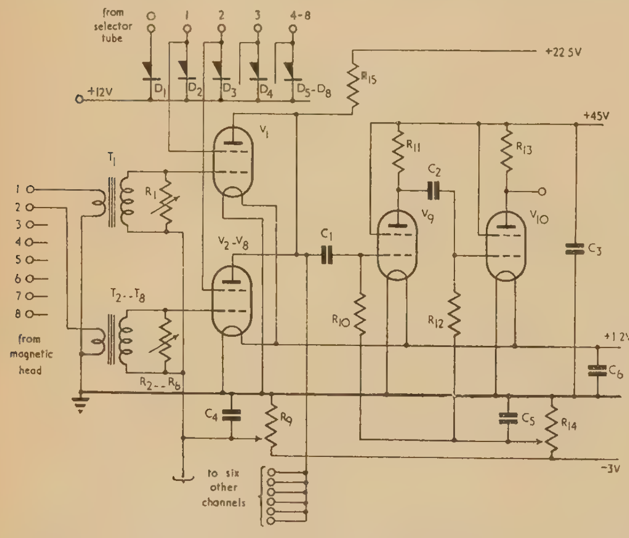


Fig. 6. Circuit diagram of electronically switched pre-amplifiers and amplifier

R_1–R_8 = 2 MΩ
R_9 = 100 kΩ
R_{10} = 1 MΩ
R_{11} = 150 kΩ
R_{12} = 1 MΩ
R_{13} = 150 kΩ

R_{14} = 100 kΩ
R_{15} = 820 kΩ

C_1, C_2 = 20 pF
C_3 = 1 μF
C_4, C_5 = 0·01 μF

T_1–T_8 = 1 : 30 Fortiphone T.4

V_1–V_8 = DL 64
V_9, V_{10} = DF 72

D_1–D_9 = GEX 45/1

which results from this type of gating is likely to upset the biasing in the amplifier. The latter is therefore given a short time constant of differentiation; the pulses from the magnetic heads are short enough for the loss of signal to be tolerable. Potentiometers on each channel enable signals to be equalized. The two potentiometers for the voltages are adjusted empirically to give the optimum of signal to interference from the gating pulses.

The tuning fork could be excited directly from the output of the selector tube but it has been found bett include a selective amplifier. This eliminates the harmonics, which might be picked up by the magnetic h and also enables the phase of the excitation to be varied small piece of magnetized steel attached to the lower of the fork induces in a fixed pick-up coil a signal whi frequency doubled and used to synchronize the phase o master oscillator.

As explained earlier a second gating operation is use separate the signals from the "pedestal" effects cause the electronic mixing. This gate is arranged so that only open when the tines of the tuning fork are movin the middle parts of their oscillations. It thus has the a tional advantage of concentrating attention on a very s section of the tape and making it easier to observe s signals. A four-diode gate, of the type described Chance,(7) is the most suitable as it shows a very s pedestal effect. Operation with germanium crystal di has proved satisfactory, provided a balancing contr included. A potentiometer which controls the amplitud the gating signal enables the width of this gate to be adjus

This equipment has been developed for reading the rec of a cosmic-ray apparatus which consists essentially of rows of four Geiger counters placed one above the ot The display of the pulses is therefore arranged in like man so that the picture on the cathode-ray tube (see Fig corresponds directly with the cosmic-ray event. The volt which must be applied to the plates of the oscilloscop order to achieve this are derived from a bi-stable ci that is triggered by the selector tube. The output of th applied directly to the other Y-plate and *via* an integra circuit to one X-plate. A switch on the bi-stable ci brings the spot to rest in the middle of the screen. In way pulses from all the channels can be superimposed each other; this is useful when searching for events, p cularly when they are relatively far apart on the tape.

OPERATION OF PLAYBACK EQUIPMENT

In setting up this apparatus the first requirement is the tape should make good contact with the head. It en found that the tape guide pulleys immediately above d below the magnetic head must be alined very carefully. ckground noise and irregular signals result if the head is t well polished and kept clean. Some varieties of magnetic pe are unsuitable for use with this equipment because the tive material is soon scraped off the backing. This does t happen with other tapes and on some occasions the fork s been allowed to vibrate the magnetic head against one

when trying to distinguish a single event from two closely separated ones. The necessity for careful adjustment of this phase shift would be avoided if the gating was arranged so that all the channels picked up signals when the head was moving in one direction. This could be achieved by operating the selector tube at only half the frequency used at present and there does not appear to be any great disadvantage in such a modification.

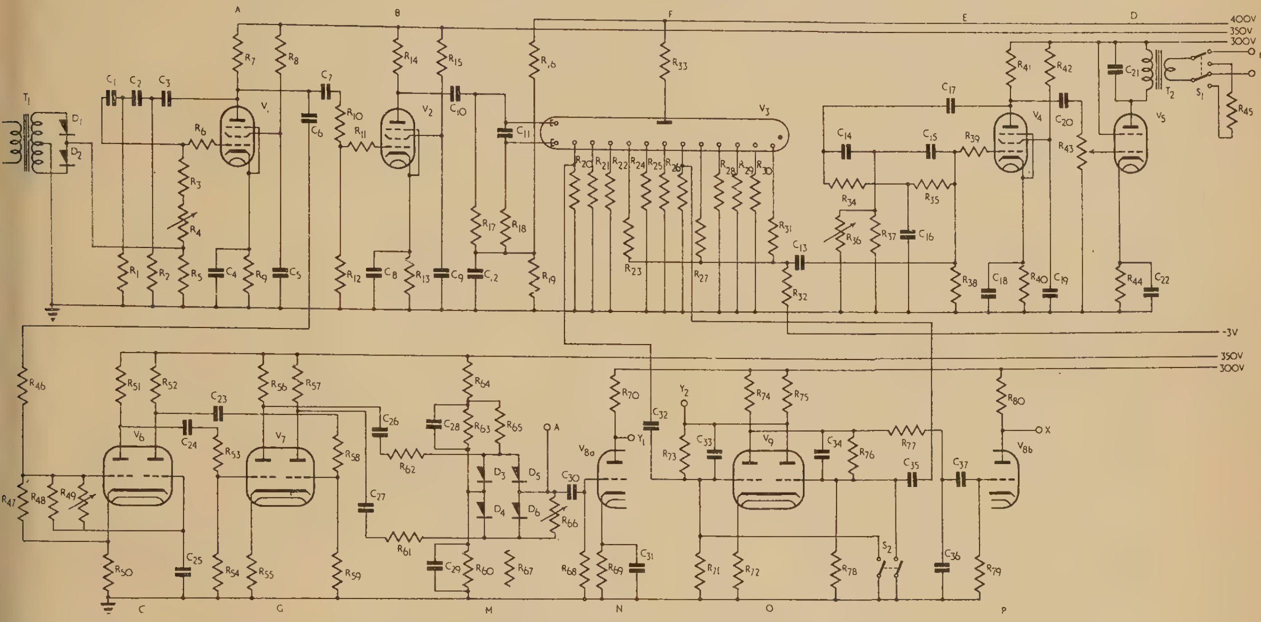

A
B
F
E
D
400V
350V
300V
tuning fork
T1
D1
D2
C1
C2
C3
R6
R3
R4
R1
R2
R5
C4
R9
C5
R7
R8
V1
C7
C6
R10
R11
R14
R15
V2
C10
C11
R16
R12
C8
R13
C9
C12
R17
R18
R19
R33
V3
R20
R21
R22
R24
R25
R26
R28
R29
R30
R23
R27
R31
C13
R32
C17
C14
C15
R39
R34
R35
R36
R37
C16
R38
C18
R40
C19
R41
R42
V4
C20
R43
C21
T2
S1
V5
R45
R44
C22
-3V
350V
300V
R46
R47
R48
R49
R50
R51
R52
V6
C23
C24
R53
C25
R56
R57
V7
R54
R55
R58
C27
C26
R62
R61
R59
R64
C28
R63
R65
D3
D5
D4
D6
C30
R66
C29
R60
R67
R68
R69
C31
V8a
R70
Y1
Y2
C32
R73
C33
V9
R74
R75
C34
R76
R77
C35
C37
C36
S2
R71
R72
R78
R79
R80
V8b
X
C
G
M
N
O
P

Fig. 7. Main electronic unit

R_1 1·2 MΩ
R_2 = 220 kΩ
R_3 1 MΩ
R_4 = 470 kΩ
R_5 = 220 kΩ
R_6 = 47 kΩ
R_7 = 33 kΩ
R_8 = 100 kΩ
R_9 = 680 Ω
R_{10} = 1·5 MΩ
R_{11} = 47 kΩ
R_{12} = 22 kΩ
R_{13} = 680 Ω
R_{14} = 33 kΩ
R_{15} = 100 kΩ
R_{16} = 2·2 MΩ
R_{17}, R_{18} = 150 kΩ
R_{19}–R_{22} = 47 kΩ
R_{23} = 68 kΩ
R_{24}–R_{26} = 47 kΩ
R_{27} = 68 kΩ
R_{28}–R_{30} = 47 kΩ
R_{31} = 68 kΩ
R_{32} = 33 kΩ
R_{33} = 390 kΩ
R_{34}, R_{35} = 150 kΩ
R_{36} = 1 MΩ
R_{37} = 100 kΩ
R_{38} = 220 kΩ
R_{39} = 47 kΩ
R_{40} = 680 Ω
R_{41} = 15 kΩ
R_{42} = 100 kΩ
R_{43} = 100 kΩ
R_{44} = 220 Ω
R_{45} = 2·2 kΩ
R_{46}, R_{47} = 2·2 MΩ
R_{48} = 18 kΩ
R_{49} = 100 kΩ
R_{50} = 82 kΩ
R_{51}, R_{52} = 150 kΩ
R_{53} = 3·3 MΩ
R_{54} = 220 kΩ
R_{55} = 680 Ω
R_{56}, R_{57} = 68 kΩ
R_{58} = 3·3 MΩ
R_{59} = 220 kΩ
R_{60} = 15 kΩ
R_{61}, R_{62} = 150 kΩ
R_{63} = 15 kΩ
R_{64}, R_{65} = 100 kΩ
R_{66} = 3 MΩ
R_{67} = 100 kΩ
R_{68} = 2·2 MΩ
R_{69} = 470 Ω
R_{70} = 47 kΩ
R_{71} = 390 kΩ
R_{72} = 2·2 kΩ
R_{73} = 1·5 MΩ
R_{74}, R_{75} = 68 kΩ
R_{76} = 1·5 MΩ
R_{77} = 560 kΩ
R_{78} = 390 kΩ
R_{79} = 1·5 MΩ
R_{80} = 68 kΩ

C_1 = 50 pF
C_2 = 120 pF
C_3 = 0·001 μF
C_4 = 50 μF
C_5 = 0·25 μF
C_6 = 0·01 μF
C_7 = 330 pF
C_8 = 50 μF
C_9–C_{11} = 0·1 μF
C_{12} = 1 μF
C_{13}–C_{15} = 0·01 μF
C_{16} = 0·02 μF
C_{17} = 0·25 μF
C_{18} = 50 μF
C_{19} = 0·1 μF
C_{20} = 0·02 μF
C_{21} = 0·25 μF
C_{22} = 50 μF
C_{23}, C_{24} = 0·01 μF
C_{25}–C_{27} = 0·1 μF
C_{28}, C_{29} = 8 μF
C_{30} = 0·01 μF
C_{31} = 50 μF
C_{32} = 300 pF
C_{33}, C_{34} = 100 pF
C_{35} = 300 pF
C_{36}, C_{37} = 0·25 μF

D_1–D_6 = OA 71

V_1, V_2 = EF 91
V_3 = GS 12 C
V_4 = EF 91
V_5 = N 78
V_6, V_7 = ECC 83
V_8, V_9 = ECC 91

ction of the tape for several hours without any deteriora- on of the signal. Care must be taken to avoid creasing the pe as any mechanical damage causes large spurious signals. Using the recording circuits described in a previous per(1) and Emitape No. 88 magnetic tape the signals on e oscilloscope have an amplitude of over 1 cm peak-to- ak; the pedestal effect due to the second gate is less than nm. Events separated by 0·1 mm along the tape can sily be resolved.

The circuits have been operated from well smoothed but stabilized supplies. After the initial warm-up period it is necessary to readjust most of the controls. The phase ntrol on the selective amplifier feeding the tuning fork es require adjustment if for any reason the tension of the pe, and hence the damping of the tuning fork, is not nstant. Any phase shift here is very undesirable as it sults in alternate channels of the head accepting signals om different regions along the tape. The small spurious lses which can usually be seen on channels adjacent to e carrying a true signal provide a useful check on the rrect setting of the phase control. They are also of value

ACKNOWLEDGEMENTS

I am indebted to Mr. E. H. McKoy of the Physics Department, University College of the West Indies, for the mechanical design and construction of much of the playback equipment. Dr. H. Mykura suggested solutions to several of the problems encountered in constructing the magnetic heads.

REFERENCES

(1) Barton, J. C. *J. Sci. Instrum.*, **33**, p. 308 (1956).
(2) Skellett, A. M., Leveridge, L. E., and Gratian, J. W. *Electronics*, **26**, p. 168 (1953).
(3) Daniel, E. D. *Proc. Instn Elect. Engrs*, *B*, **102**, p. 442 (1955).
(4) Sorrels, J. R. *N.B.S. Tech. News Bull.*, **39**, p. 116 (1955).
(5) Daniel, E. D. *Proc. Instn Elect. Engrs*, **100**, (3), p. 168 (1953).
(6) Brit. Pat. Appl. No. 25223/55.
(7) Chance, B. Chap. 10, p. 375, *Waveforms* (New York: McGraw-Hill Book Co. Inc., 1949).

Simple equipment for a small low temperature laboratory

By R. F. Broom, B.Sc., and A. C. Rose-Innes, M.A., D.Phil., Services Electronics Research Laboratory, Baldock, H

[*Paper first received* 9 *May, and in final form* 13 *July*, 1956]

Until recently low temperature research has been chiefly carried out in those laboratories having the complicated apparatus needed to liquify hydrogen or helium. It has now become possible to buy liquid helium from the National Physical Laboratory and this paper describes simple and versatile low temperature equipment designed to use this helium. The temperature range in which experiments can be carried out is from 1·3 to 33° K. The paper is intended for those not already familiar with low temperature techniques.

1. INTRODUCTION

Equipment for producing low temperatures (say from 90 to 1° K) can be a very useful addition to the facilities of a laboratory. Such temperatures are obtained by the use of liquid hydrogen (20° K) and liquid helium (4·2° K) so, until recently, low temperature research has been confined to those specialized laboratories which had the rather complicated equipment necessary to make these liquified gases. In the last few years, however, commercial helium liquifiers have become available, and at the beginning of 1955 a scheme was started whereby a number of laboratories could use liquid helium supplied by a Collins helium liquifier installed at the National Physical Laboratory. The Services Electronics Research Laboratory is the first establishment in this country to have low temperature research equipment depending entirely on such an external supply of liquid helium, hence a description of the methods and equipment used may be of interest. The equipment described is of a simple nature since the installation is intended as an additional facility to a laboratory not primarily engaged in low temperature work.

2. STORAGE AND DISTRIBUTION OF HELIUM

Liquid helium is delivered from the National Physical Laboratory to this laboratory in a metal storage Dewar vessel having a capacity of 16 l. Helium is a valuable substance, so all the gas which boils off the liquid must be collected and, furthermore, must be kept free from contamination with air. The helium gas which accumulat therefore stored in gas-holders, pumped into high-pres cylinders and returned to the N.P.L.

Fig. 1 shows the metal storage Dewar vessel (obta from Dupree Swift, London), which is based on a desig the Radar Research Establishment. The liquid heliu contained in an inner Dewar vessel *H* surrounded by li oxygen *O*. The tube *T* on which the helium Dewar v hangs, is made of stainless steel of diameter $\frac{3}{4}$ in. and thickness 0·007 in. About 200 cm^3 of liquid helium evapo from this Dewar vessel in twenty-four hours. The vess sufficiently strong to be transported by lorry or (subjec certain legal requirements) by rail. The increase in the of evaporation of the liquid helium due to jolting du transport seems to be negligible.

The storage vessel is normally connected to the low pres return pipe (*D*, Fig. 2) and the gas which boils off is colle in low pressure gas-holders. These consist of rubber fabric cylinders each of about 0·6 m^3 volume when infla they are, in fact, pneumatic fenders for flying-boats. rate of diffusion of helium gas out of these is small, al 5 l. of gas in twenty-four hours. The gas-holders are pended from the ceiling. A small modified two-s compressor, housed outside the building, pumps the hel gas from the gas-holders into high-pressure cylinders pressure of 30 atm for transport back to the N.P.L. At eight "200 ft^3" U.S. helium cylinders are needed to con the gas from 16 l. of liquid helium.

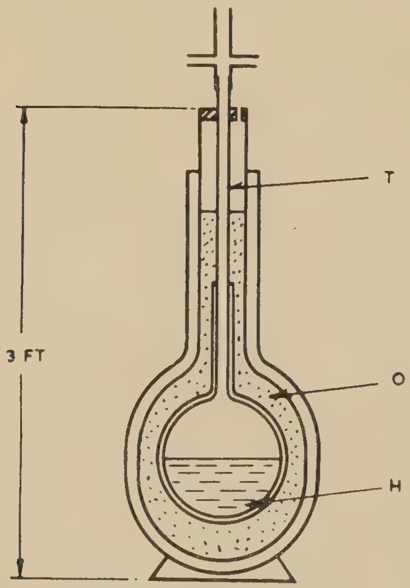


Fig. 1. The metal helium storage Dewar vessel

3. THE LOW TEMPERATURE APPARATUS

(*a*) *Design considerations*

(i) *Versatility.* In most low temperature laboratorie special apparatus is constructed for each kind of experim In a small low temperature section, however, this is possible, so it was decided to try to design one versa apparatus which could be used for a variety of experime This would in effect be a very low temperature "refrigerat inside which different measurements could be carried out

(ii) *Cooling liquids.* It was decided to use only lic helium and liquid oxygen for coolants and not to make of liquid hydrogen. Though this makes it more difficul cover the temperature range from 4·2 to 90° K, the appar is more convenient without the safety precautions neces when using liquid hydrogen and, furthermore, there is present no commercial supply of liquid hydrogen availabl

(iii) *Temperature range.* The aim was to get as wid temperature range as possible, without using very complic equipment. Moreover, the temperature should be conti ously variable within this range. It was thought tha should be possible to design an apparatus which would temperatures between 90 and $1\frac{1}{2}$° K, the lowest temperat

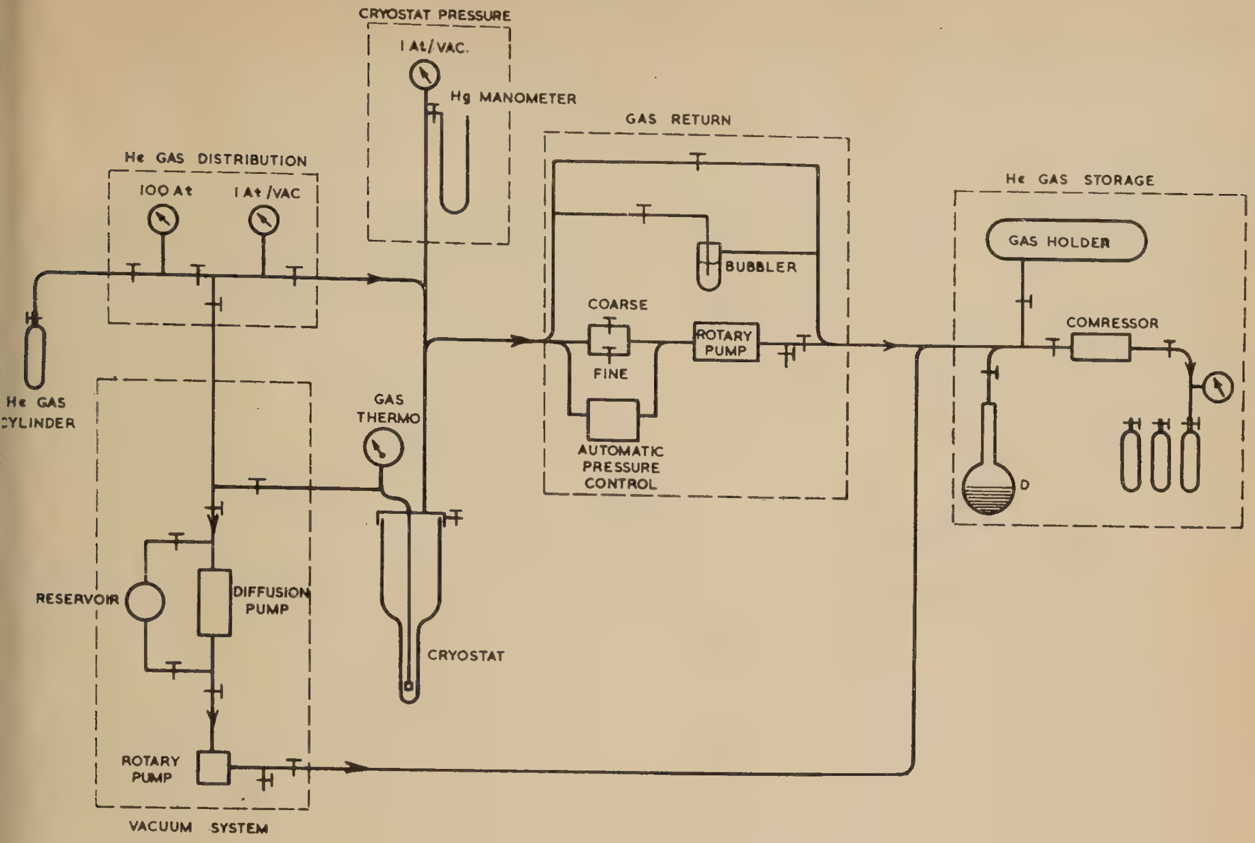

CRYOSTAT PRESSURE
1 At/VAC.
Hg MANOMETER
GAS RETURN
He GAS DISTRIBUTION
100 At
1 At /VAC
He GAS STORAGE
GAS HOLDER
BUBBLER
COARSE
ROTARY PUMP
COMRESSOR
FINE
AUTOMATIC PRESSURE CONTROL
He GAS
CYLINDER
GAS THERMO
D
RESERVOIR
DIFFUSION PUMP
CRYOSTAT
ROTARY PUMP
VACUUM SYSTEM

Fig. 2. Low temperature installation

ich can be reached with moderately sized rotary pumps e Section 3(*d*)].

The cryostat

The cryostat is shown in Fig. 3. An inner double-walled rex glass vessel D_1 contains the liquid helium. Around s is a Dewar vessel D_2 which is full of liquid oxygen.

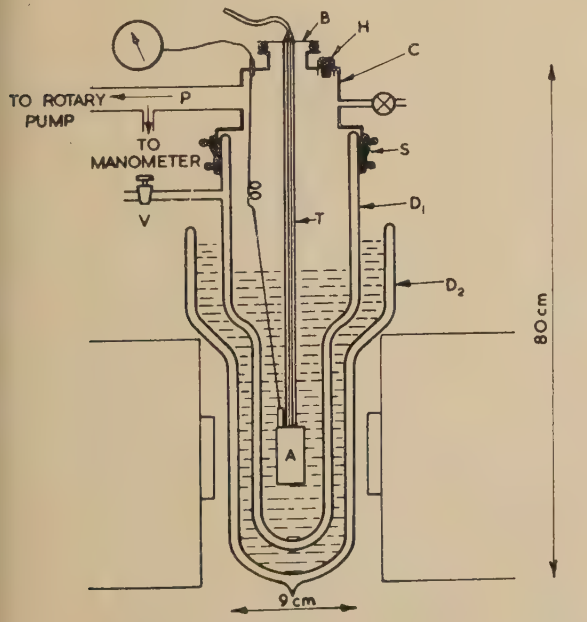

B
H
C
TO ROTARY PUMP
P
TO MANOMETER
S
V
D_1
T
D_2
A
80cm
9cm

Fig. 3. Diagram of cryostat

Many experiments require the application of a magnetic field, and so these vessels have a narrow tail in order that the cryostat can be placed between the poles of a magnet. Both D_1 and D_2 are silvered but a clear slit runs vertically from top to bottom so that it is possible to see into the apparatus. Vessel D_1 is sealed to the brass cap *C* by a rubber sleeve *S*.

The specimen being measured is usually contained in a copper calorimeter *A* supported on the end of a thin stainless steel tube *T*, any electrical leads being taken out through a seal at the top. It is, of course, important that any metal tubes going into the low temperature part should be of low thermal conductivity material. Alloys such as stainless steel and nickel silver are best for this purpose. Furthermore, all connexions to the low temperature region must be gas-tight in order that air cannot leak in and condense onto the apparatus. The apparatus *A* (Fig. 3) can easily be changed by undoing the O-ring seal at *B* and withdrawing *A* on the end of its supporting tube *T*.

It is necessary to pre-cool the calorimeter and the inside of D_1 before syphoning in liquid helium. This is done by admitting air between the walls of D_1 through the tap *V*, when the contents will cool to the temperature of the liquid oxygen in D_2. Before filling D_1 with liquid helium this air is pumped out by a rotary pump and the tap *V* closed. When the liquid helium is syphoned in, any residual air between the walls of D_1 will solidify, leaving a very good vacuum and thermal insulation. This method is used because most glasses are permeable to helium, and a sealed-off Dewar vessel for holding the liquid helium would frequently need re-evacuating. It also allows the pre-cooling to be carried out very easily. Vessel D_1 can hold about 1 l. of liquid helium but it is usually not necessary to use more than about ½ l., which is sufficient in most experiments to give low temperatures for a whole afternoon.

A bubbler (see Fig. 2) containing butyl phthalate is included in the pipe from the cryostat to the gas-holder to give an indication of the rate at which the liquid helium in the cryostat is evaporating when it is not being pumped. Also included in the apparatus is a vacuum system, consisting of a mercury diffusion pump and rotary pump, for evacuating the gas thermometer [see Section 3(*e*)] and any apparatus requiring high vacuum.

(*c*) *Syphoning the liquid helium*

Fig. 4 shows the metal syphon used to transfer the liquid helium from the storage vessel to the cryostat. The helium flows through the 4 mm diameter thin-walled German silver tube *TT* which is surrounded by a vacuum jacket *J*, the legs of which are also of German silver. The short rubber sleeves *S* form gas-tight seals to the storage vessel and cryostat while the liquid helium is being transferred.

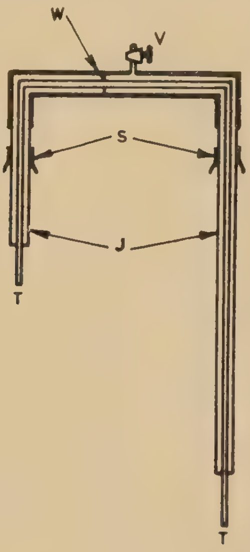


Fig. 4. The liquid helium syphon

The method of filling the cryostat is illustrated in Fig. 5. The storage Dewar vessel is brought to the cryostat and connected to it by a rubber tube attached to the val With *X* open, the syphon is lowered into position and then closed. Due to the liquid boiling off in the st Dewar vessel, an over-pressure is built up there an liquid is forced through the syphon into the cryostat. rate of flow may be increased by squeezing the fo bladder *B*. When the contents of the cryostat have c to 4·2° K, liquid helium collects in the bottom. Th which is evolved during transfer flows through the out into the gas-holders. When sufficient liquid has been t ferred, the flow can be stopped by opening valve *X* v equalizes the pressure in the two vessels. The syphon now be withdrawn and the holes closed with rubber bun

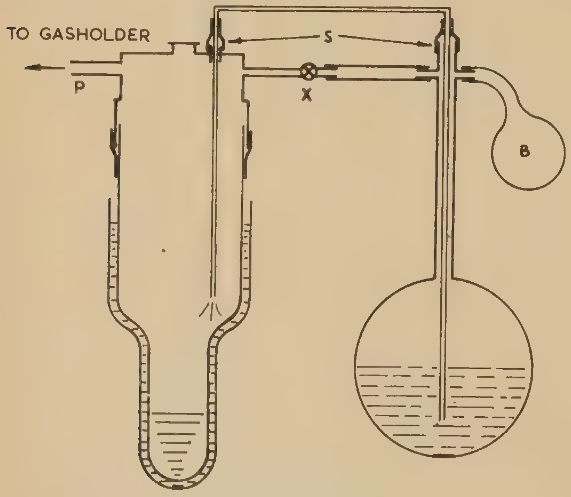


Fig. 5. Syphoning the liquid helium

(*d*) *Temperature range*

(i) *Temperature below 4·2° K.* The temperature o liquid helium can be lowered by reducing the pressure the surface. This is done by pumping D_1 through the p (Fig. 3), and the temperature can then be controlled by v in the pumping line ("coarse" and "fine," Fig. 2). Us rotary vacuum pump with a speed of 150 l./min and pi 1 in. diameter it is possible to reduce the vapour pre above the liquid helium to 1·5 mm of mercury, which responds to a temperature of 1·33° K [see Section 3(*e*)]. temperature can be held constant at any value by adjustment of the "fine" needle valve.

It is often convenient to have automatic control o temperature. An automatic pressure control has, there been added in parallel with the manual control. This co of a pressure operated valve which maintains the pressu the input side constant, holding the temperature of the helium steady to about 1/100° K.

(ii) *Temperature above 4·2° K.* Temperatures sli above that of liquid helium are somewhat difficult to ob as there is, unfortunately, no liquid to act as a coolan this range. The minimum temperature which can be obta by pumping liquid hydrogen is about 10° K and the r between this and 4·2° K must be covered by special met Various devices are described in the literature for cove this range, most of which depend on having the calorimet poor thermal contact with liquid helium and heatin electrically to the desired temperature.

A very simple device for obtaining temperatures a 4·2° K based on Simon's desorption method of obtai low temperatures is used at this Laboratory.(1) A deta description of the device has already been published(2, only a brief outline is given here.

Attached to the calorimeter is a pot containing activ charcoal (Fig. 6). The apparatus is cooled to 4·2° K pouring on liquid helium and the charcoal becomes satur with adsorbed helium. After the liquid helium has boiled off, the rate of desorption of the helium gas ca adjusted to balance the temperature rise of the cryostat. this means temperatures from 4·2 to 33° K can be constant to within about 1% for considerable periods. time for which a given temperature can be mainta depends, of course, on the heat being generated in apparatus, but with the apparatus used a temperatur 30° K can be maintained for ½ hour when 100 mW of hea being generated by the experiment in the calorimeter. Lc temperatures can be maintained for longer periods.

(*e*) *Temperature measurement*

Temperatures below 4·2° K are determined by measu the vapour pressure of the boiling helium and using publis tables.(4) This pressure is measured by means of a si tube mercury manometer connected to the pumping line P gs. 2 and 3).

Temperatures above that of liquid helium are measured by imple gas thermometer, consisting of a bulb attached to calorimeter, and connected by a very thin German silver pillary tube to a standard Bourdon pressure gauge (the bulb the spiral in Fig. 6). The thermometer is filled at room

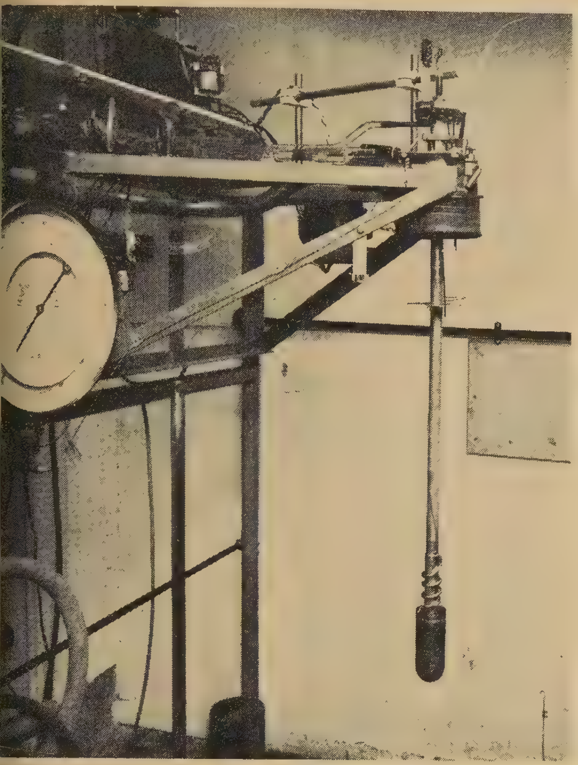


Fig. 6. Cryostat with Dewar vessels removed, showing charcoal desorption pot and gas thermometer

nperature with helium gas at atmospheric pressure. The ssure is also measured with the bulb immersed in liquid ygen and the calibration curve can then be calculated down 4° K by using the perfect gas laws. The error in assuming gas to be perfect amounts to only about 1% at 4° K.

4. AUXILIARY EQUIPMENT

The level indicator

n order to measure how much liquid helium there is in storage Dewar vessel some form of level indicator must used. The authors have used the particularly simple device cribed by Gaffney and Clement.(5) It consists of a dipk of 2½ mm diameter German silver tube, open at the tom and closed at the top by a drum over which is tched a rubber membrane. When the dipstick is lowered o the liquid helium container the temperature gradient sets thermal oscillations of the gas and the rubber membrane rates strongly. When the dipstick touches the surface of liquid the oscillations undergo an abrupt and marked nge in frequency which is easily detected by a finger.

The helium gas purity tester

t is important to know that the helium gas pumped into high pressure cylinders has not become contaminated, so ery simple instrument for measuring the purity of gaseous helium has been devised. This instrument, shown in Fig. 7, consists of a long German silver tube T, closed at the lower end by a copper cap. At the top is a brass manifold connected to a small mercury manometer M and a valve V leading to a rubber football bladder B and two side-arms P and C. With the valve V open the instrument is connected to the cylinder of gas to be tested and to a rotary vacuum pump by rubber tubes connected to C and P respectively. The instrument is then evacuated by the rotary pump. The helium gas to be tested is now admitted slowly until it is at atmospheric pressure, which can be detected by the bladder B beginning to inflate. Valve V is then closed and the tube T is lowered down the neck of the storage Dewar vessel. Any gases present other than helium will solidify at the bottom of T with a very small vapour pressure. Valve V is now opened and the helium gas is pumped out, leaving the solid impurities behind. When the manometer shows zero pressure, V is closed, the instrument is taken out of the storage Dewar vessel and, on warming up, the impurity gases vaporize. The pressure finally shown by the manometer M indicates the amount of contamination present.

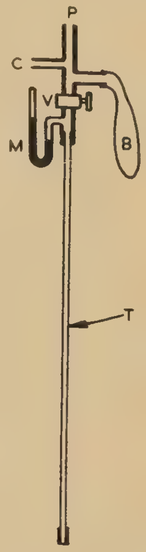


Fig. 7. The helium gas purity tester

5. COST

The cost of the whole low temperature installation is not very easy to estimate. That of items purchased outside the laboratory was about £600 but it is difficult to estimate the cost of items drawn from stores or made in the laboratory workshop. As a rough figure the total cost is estimated to be about £750.

At present the National Physical Laboratory charges £4 per litre for liquid helium but allows a rebate of 1*s*. per ft^3 for the helium gas which is returned (the full rebate is only paid if the purity of the returned gas exceeds 98%). The net cost of liquid helium is therefore £3 per litre. At this laboratory about 6 l. are used every fortnight.

The equipment described in this article has been in continual operation for about a year, during which time it has proved reliable and easy to operate. Its versatility has allowed experiments to be carried out at low temperature on Hall coefficient, superconductivity, fluorescence and cyclotron resonance.

ACKNOWLEDGEMENTS

We are grateful to Mr. I. M. Ross for his interest in this work and to the staffs of the Clarendon Laboratory, Oxford, the Royal Society Mond Laboratory, Cambridge, and the Physics Division of the Radar Research Establishment, Malvern, for their advice and many helpful discussions. The pneumatic fenders for flying boats which were used as low pressure gas-holders were kindly supplied by the R.A.F. Station, Cardington. Acknowledgement is made to the Admiralty for permission to publish this paper.

REFERENCES

(1) Simon, F. E. *Physica*, **4**, p. 879 (1937).
(2) Jackson, L. C., and Preston-Thomas, H. *J. Instrum.*, **28**, p. 99 (1951).
(3) Rose-Innes, A. C., and Broom, R. F. *J. Sci. Instr* **33**, p. 31 (1956).
(4) For example, Squire, C. F. *Low Temperature Ph* (London: Methuen and Co. Ltd., 1946).
(5) Gaffney, J., and Clement, J. R. *Rev. Sci. Instrum* p. 620 (1955).

An instrument for the measurement of salinity in estuaries

By E. G. Sandels, Grad.I.E.E., Hydraulics Research Station, Howbery Park, Wallingford, Berks

[*Paper first received* 25 *October*, 1955, *and in final form* 11 *May*, 1956]

The instrument described was designed for salinity measurements in estuaries. It is carried in a boat, water being pumped through it from an intake which is lowered into the estuary. Electrical conductivity and temperature are measured and the salinity is computed readily from a nomogram. Radio-frequency circuits are employed for the measurements, the indicator being a milliammeter operated from a d.c. amplifier. The accuracy is better than ±¼ parts per thousand over a salinity range of from 0·2 to 50 p.p.t.

1. INTRODUCTION

In the work at Hydraulics Research Station knowledge of the salinity distribution in estuaries is sometimes of considerable importance, having a bearing not only on current directions and velocities but also on the rate of silt deposition due to flocculation.

Initially an instrument was required for recording salinity in selected regions of the Thames estuary. The instrument described is operated by hand but was developed as the basis of a self-recording instrument now under construction at Hydraulics Research Station. The electrical conductivity of water depends on the salt concentration and the temperature. In this instrument the electrical conductivity and the temperature of the estuary water are measured separately and the salinity is determined from a nomogram relating these two quantities.

Radio-frequency current is employed in the instrument for the measurements. This has the same advantage as that gained by the use of alternating currents of lower frequencies in that polarization effects between the electrodes and the liquid are reduced. Also the electrodes may be mounted outside the conductivity tube; this advantage is considerable as the instrument is often required to deal with mud-laden water, the bane of electrode contamination is removed and cleaning is much simpler. Employment of radio frequencies for the measurement of liquid conductivity has been made in the past, notably by Blake(1) and McCourt,(2) and in both methods the actual measurement was of power absorbed from an oscillator by the resistance of the liquid under measurement. This has three disadvantages:

(i) The relation between power absorbed and conductivity is linear for small ranges only.
(ii) The amount of power absorbed depends on the age of the oscillator valve.
(iii) The measurement is indirect.

In the method followed here the oscillator supplies a novel circuit comprising the conductivity tube and a linear variable capacitor. The voltages developed across each are recti and subtracted, and for zero difference there is a us relationship between capacitance and conductivity. T relationship is linear over most of the range and the depar from linearity over the remainder is not significant for accuracy required.

The temperature of the liquid is measured by a merc thermometer which is inserted in the flow, the capacita between the mercury column and an electrode round stem being measured in a circuit similar to that utilized in conductivity measurement. This indirect and appare complicated method is not a practical necessity for the ha operated salinometer, but it is one of great convenience the salinity recorder; it has been used in the former instrum by way of a trial.

Salinity is computed with a nomogram (Fig. 6) deri from published data(3) for conductivity against temperat and salinity. Some extrapolation was necessary from available data, also the intersection groups determining salinity scale were obtained graphically; this sets a limit

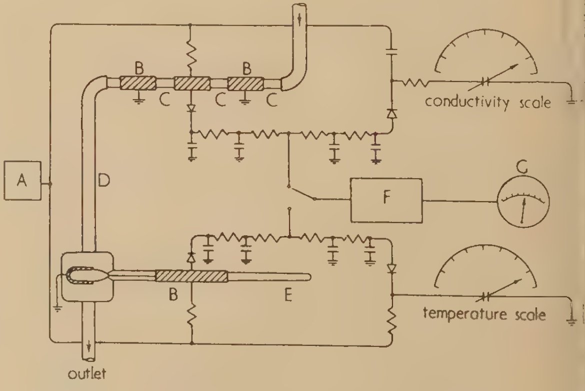


Fig. 1. Schematic circuit of salinometer

e accuracy attainable but the limit is well within that quired of the instrument.

Copper electrodes were built on to the glass walls of the nductivity tube and the thermometer by means of an ectroplating technique; this is described in Appendix 1.

2. DESCRIPTION

2(*a*). *General.* A schematic circuit and detailed circuit are own in Figs. 1 and 2. Estuary water is pumped through e conductivity tube and the T-junction containing the ermometer bulb. The conductivity tube and the thermometer form part of the conductivity and temperature measurg circuits respectively. Both of the radio-frequency voltages appearing at their electrodes are balanced against similar voltages developed across variable capacitors mounted between the conductivity and temperature cells and the front panel. The capacitors are housed in screening boxes and these with their associated components are referred to as the balancing circuits. The voltage developed in each balancing circuit is subtracted from that developed in the corresponding measuring cell, and either of the difference voltages may be switched to a d.c. amplifier operating a centre-zero milliammeter; this indicates zero when the circuit selected is in balance. The variable capacitors are on a common spindle with a directly calibrated dial, a ganged switch mounted underneath selecting the conductivity range required. A 50 c/s power pack is included; this supplies h.t. and heater

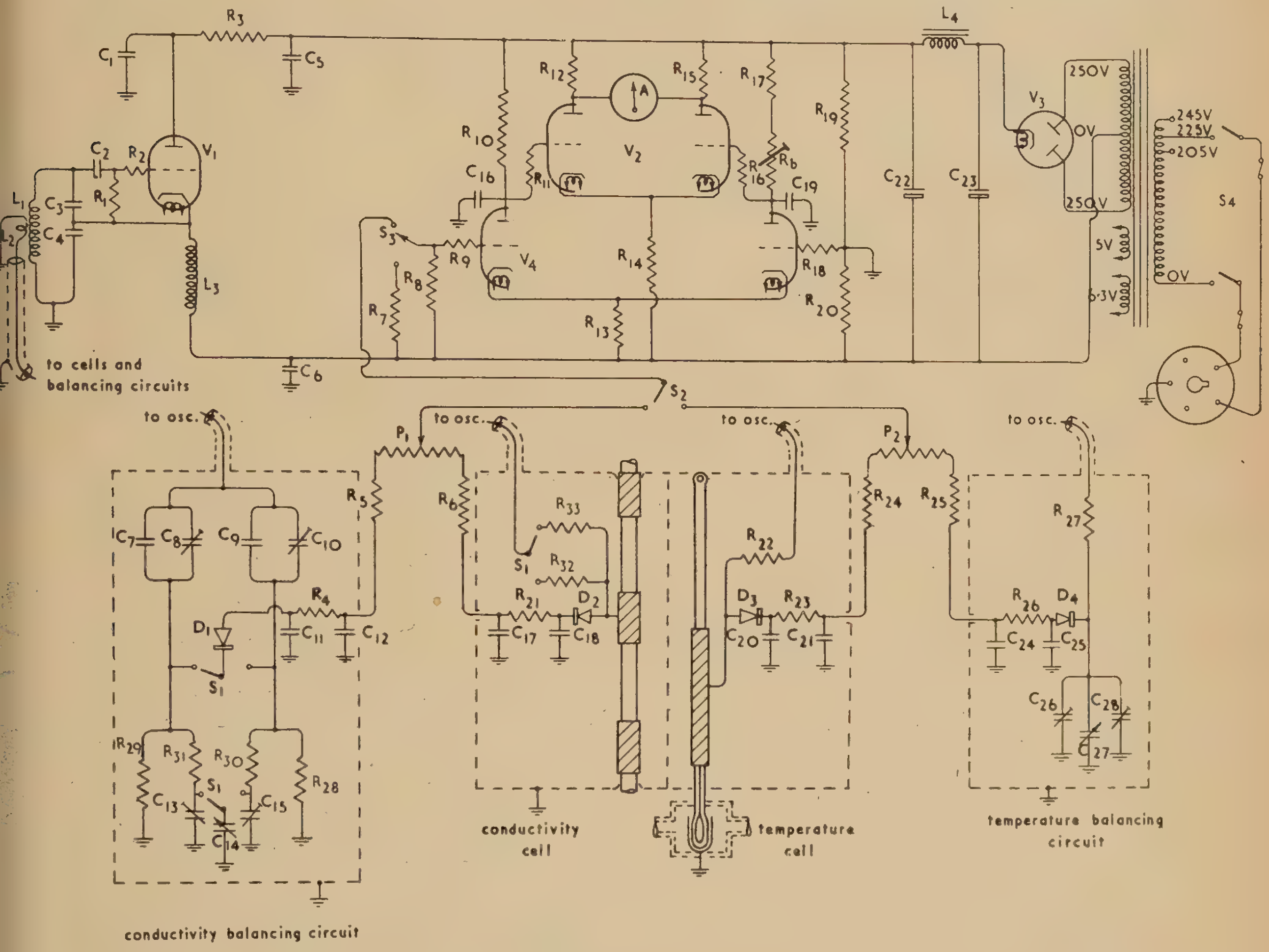

R3
C1
C5
C2
R2
V1
L1
C3
R1
C4
L2
L3
to cells and balancing circuits
C6
R10
C16
R12
A
R15
R17
R11
V2
R16
Rb
C19
R19
S3
R9
V4
R8
R7
R14
R13
R18
R20
L4
250V
V3
OV
250V
5V
6·3V
245V
225V
205V
OV
S4
C22
C23
S2
to osc.
C7
C8
C9
C10
R4
D1
C11
C12
S1
R29
R31
R30
R28
C13
C14
C15
conductivity balancing circuit
P1
R5
R6
R33
S1
R32
R21
D2
C17
C18
conductivity cell
R22
D3
R23
C20
C21
temperature cell
P2
R24
R25
R27
R26
D4
C24
C25
C26
C28
C27
temperature balancing circuit

Fig. 2. Detailed circuit of salinometer

$R_1 = 4{\cdot}7$ kΩ, $\frac{1}{4}$ W
R_2, $R_3 = 1$ kΩ, $\frac{1}{4}$ W
$R_4 = 100$ kΩ ± 1%, $\frac{1}{4}$ W
R_5, $R_6 = 470$ kΩ ± 1%
$R_7 = 270$ kΩ, $\frac{1}{4}$ W
$R_8 = 2{\cdot}2$ MΩ, $\frac{1}{4}$ W
$R_9 = 1$ kΩ, $\frac{1}{4}$ W
$R_{10} = 47$ kΩ, $\frac{1}{4}$ W
$R_{11} = 1$ kΩ, $\frac{1}{4}$ W
R_{12}, $R_{13} = 2{\cdot}2$ kΩ, $\frac{1}{2}$ W
$R_{14} = 22$ kΩ, 1 W
$R_{15} = 2{\cdot}2$ kΩ, $\frac{1}{2}$ W
$R_{16} = 1$ kΩ, $\frac{1}{4}$ W
$R_{17} = 22$ kΩ, $\frac{1}{2}$ W
$R_{18} = 1$ kΩ, $\frac{1}{4}$ W
$R_{19} = 330$ kΩ, $\frac{1}{4}$ W
$R_{20} = 10$ kΩ, $\frac{1}{4}$ W
$R_{21} = 100$ kΩ ± 1%, $\frac{1}{4}$ W

$R_{22} = 8{\cdot}2$ kΩ
$R_{23} = 100$ kΩ ± 1%, $\frac{1}{4}$ W
R_{24}, $R_{25} = 470$ kΩ ± 1%
$R_{26} = 100$ kΩ ± 1%, $\frac{1}{4}$ W
$R_{27} = 470$ Ω
$R_{28} = 38$ Ω
$R_{29} = 1{\cdot}2$ kΩ
$R_{30} = 5$ Ω
$R_{31} = 39$ Ω
$R_{32} = 6{\cdot}8$ kΩ
$R_{33} = 560$ Ω

$R_b = 50$ kΩ

P_1, $P_2 = 100$ kΩ

$C_1 = 0{\cdot}05$ μF
C_2, $C_3 = 47$ pF
$C_4 = 10$ pF
C_5, $C_6 = 0{\cdot}05$ μF
$C_7 = 110$ pF
$C_8 = 3$–30 pF
$C_9 = 110$ pF
$C_{10} = 3$–30 pF
C_{11}, $C_{12} = 0{\cdot}001$ μF
$C_{13} = 2$–15 pF
$C_{14} = 10$–300 pF
$C_{15} = 2$–15 pF
$C_{16} = 0{\cdot}01$ μF
C_{17}, C_{18} $0{\cdot}001$ μF
$C_{19} = 0{\cdot}01$ μF
C_{20}, $C_{21} = 0{\cdot}001$ μF
C_{22}, $C_{23} = 4$ μF
C_{24}, $C_{25} = 0{\cdot}001$ μF

$C_{26} = 3$–30 μF
C_{27} (C_T) = modified variable capacitor 10–45 pF
$C_{28} = 3$–10 pF

V_1 = CV133
V_2 = CV455
V_3 = CV493

L_1 = 26 turns, 30 s.w.g., 1 in. diameter, $\frac{3}{4}$ in. length
L_2 = 1 turn, 18 s.w.g., 1 in. diameter, $\frac{3}{4}$ in. length
L_3 = r.f. choke
L_4 = 8H, 120 mA

D_1–D_4 = GEX 54

A = 2–0–2 mA

voltages to the d.c. amplifier and the oscillator. Each of the balancing circuits and measuring cells is screened separately and the rectified output from each is filtered.

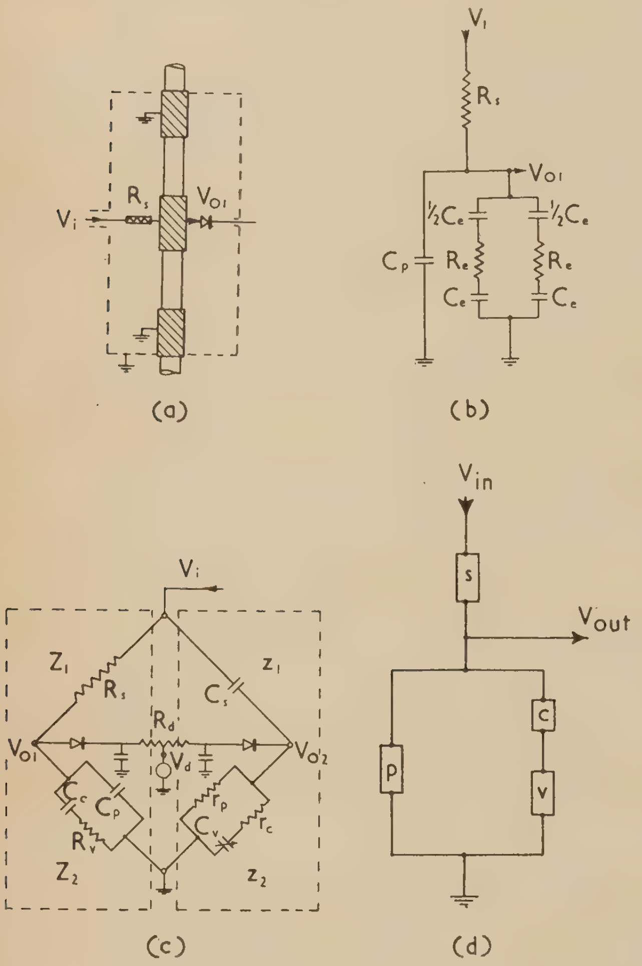


Fig. 3. The function of the conductivity cell

(*a*) Conductivity cell; (*b*) equivalent circuit of conductivity cell; (*c*) bridge formation used; (*d*) arrangement of impedances.

2(*b*). *Conductivity measurement.* In Figs. 3(*a*) and (*b*) a sketch of the conductivity tube and its equivalent circuit is shown. C_e is the capacitance between electrode and liquid and R_e the resistance of the liquid in either half of the tube, C_p is the stray capacitance between the central electrode and the screening walls of the cell. The oscillator voltage V_i is applied through a resistance R_s to a central electrode and at each end similar electrodes provide a return path. The voltage V_{01} developed at the central electrode is rectified with a germanium rectifier giving a voltage across a condenser equal to its peak value. A voltage is developed similarly from the variable capacitor c_v in the balancing circuit, this is rectified to opposite polarity and the two voltages are subtracted in a resistance chain, half their difference appearing at the centre-tap. In Fig. 3(*c*) a skeleton diagram of the conductivity measuring circuit is shown. It has the form of a bridge but unlike other a.c. bridges no account is taken of the phase difference across it, balance is obtained for equal amplitudes only. In Fig. 3(*c*), C_c is the total effective capacity between electrodes and liquid and R_v is the total effective resistance of the liquid. In the balancing circuit the functions of resistance and capacitance are interchanged, c_v correspc ing to R_v, r_c to C_c and r_p to C_p. This combination is through a capacitor c_s corresponding to R_s in the conducti cell. The advantage gained from the interchange is that balancing element c_v is a variable capacitor which is a stand and inexpensive component. A conventional bridge cir would require a variable resistance as the balancing elem and at radio frequencies this would be an expensive item. Appendix 2 the balance conditions are shown to be:

$$\frac{1}{2.\pi f.c_v} = K.R_v$$

$$\frac{1}{2.\pi.f.c_s} = K.R_s$$

$$r_p = K\cdot\frac{1}{2.\pi.f.C_p}$$

$$r_c = K\cdot\frac{1}{2.\pi.f.C_c}$$

where K is a constant

R_v, R_s, r_p and r_c are resistance values (Ω)
c_v, c_s, C_p and C_c are capacitance values (F)
f is the frequency (c/s).

Now $R_v = \frac{1}{2}.L/\sigma.a$ which is the effective resistance ot liquid in the conductivity tube.

where L = length between electrodes (cm)
a = internal cross-sectional area of the tube (cm^{2}
σ = conductivity of the liquid (mhos.cm^{-1})

then from the balance conditions:

$$\frac{1}{2.\pi.f.c_v} = \frac{K}{2}\cdot\frac{L}{\sigma.a}$$

$$\text{and } c_v \propto \sigma$$

If c_v is made a linear variable capacitance, the dial sett should be proportional to conductivity, this is approximat true but in the foregoing conditions for balance it is assum that the effective electrode capacity is independent of resistance of the liquid; in fact the capacitance is distribu along the tube and the effective value may be expected alter with the liquid resistance. In practice it is possible correct for non-linearity offsetting the values of c_v and c_s means of trimming condensers. Fig. 4(*b*) shows the capacit setting rectifier-voltage relationship for each range w voltages obtained from the conductivity tube superimpos Fig. 5 shows the calibration curves for both ranges; the sa linearly divided scale is used for each, this being sufficien accurate for requirements.

2(*c*). *Temperature measurement.* A mercury-in-glass th mometer was adapted for use in a circuit similar to that us for conductivity measurement, cylindrical copper electro being mounted around the outside of the glass stem and bu This arrangement forms a capacitance; the mercury colun provides a link between the electrodes the value of t capacitance depending on the length of the column unc the stem electrode, the thermometer has a linear scale a the capacitance is proportional to the temperature of the bu

The thermometer electrode is connected through a resistar to the r.f. oscillator and in the temperature balancing circ a linear variable capacitor is connected similarly. The voltag appearing across the capacitor and the thermometer electroc respectively are rectified and subtracted, the difference volta ng connected to the d.c. amplifier as described; for balance variable capacitor setting has a linear relation with nperature. Fig. 4(*a*) shows the capacitor-setting rectifier-tage relationship with voltages from the thermometer ctrode superimposed.

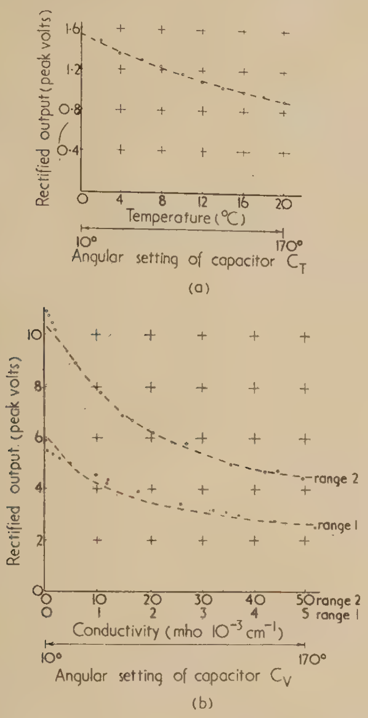


Fig. 4. (*a*) Output voltage curve for temperature cell
○ temperature cell
— — — balancing circuit

(*b*) Output voltage curves for conductivity cell
○ conductivity cell
— — — balancing circuit

2(*d*). *Radio-frequency oscillator.* This is a Colpitts oscil-or of conventional design. An oscillation frequency of Mc/s was chosen as being high enough to make the pacitative reactance between the electrodes and liquid all compared with the resistance of the liquid. The con-ctivity measuring system depends for its accuracy upon nditions of low distortion; to reduce distortion the oscillator lightly loaded, the radio-frequency power required for the eration of the instrument being less than ½ W. Details are en in the circuit diagram in Fig. 2, the output from the gle turn of the output winding on the oscillator is approxi-tely 8 V (r.m.s.) and this is conducted through screened bles to each of the balancing circuits and measuring cells.

2(*e*). *D.C. amplifier.* Either of the voltage differences tween the balancing circuits and the conductivity and nperature cells respectively may be fed into a d.c. amplifier ich operates a centre zero milliammeter on the front panel. e voltage differences which appear at the sliders of potentio-ters P_1 and P_2 may be switched *via* S_2 and S_3 to the grid a long-tailed pair amplifier (see Fig. 2). The anodes of first stage are connected to the grids of the second stage, milliammeter being connected in the anode circuit of the ond stage. A variable resistor R_b in the anode circuit of first stage enables adjustment of the electrical zero of the trument.

In terms of the milliammeter current and the input voltage the sensitivity of the amplifier is approximately 100 mA/V. As the meter reaches a full-scale deflexion for a current of 2 mA it will clearly indicate if the rectified voltages differ by as little as 1/1000th part of a volt.

2(*f*). *Power supply.* A transformer, rectifier and filter are included in the instrument, these will deliver up to 60 mA at 250 V d.c. The instrument may be operated directly off the 50 c/s 230 V main or from a 12 V d.c. to 230 V a.c. vibratory convertor. The total power consumption of the instrument is 30 W and this is well within the capability of the convertor provided.

3. CALIBRATION AND OPERATION

3(*a*). *Operation.* Operation is simple. The water under measurement is pumped through the instrument from an intake in the estuary. Before measuring, the amplifier is balanced by switching S_3 and adjusting the balance resistor R_b for zero on the output meter; this should be some minutes after the instrument is switched on. After balancing, temperature and conductivity is measured by switching S_2 to either bridge and adjusting the main dial for balance. Two conductivity ranges are available. Range 1 0·2–5·0 and Range 2 2·0–50·0 (mho. 10^{-3} cm^{-1}). If higher accuracy is required the calibration curves should be used. Range 1 is preferable for all conductivities below 4 mho. 10^{-3} cm^{-1}.

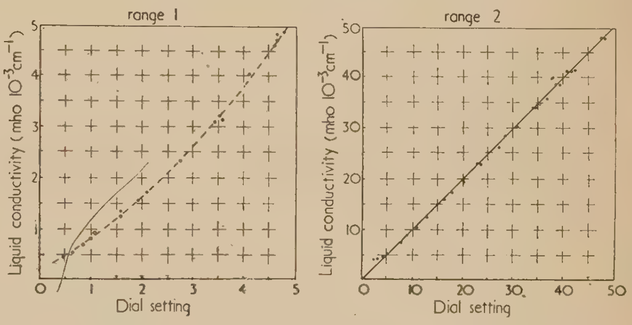


Fig. 5. Calibration curves for conductivity measurement

3(*b*). *Calibration.* The instrument was adjusted initially by calibrating it against a commercial conductivity bridge. A solution of sodium chloride and distilled water was used which was strengthened in steps until the entire conductivity range had been covered. This was found to be a rapid and convenient way for adjusting the component values in the balancing circuit. However, a final calibration was made by using standard solutions before the instrument was used for actual measurements.

Before setting the balance circuit trimming capacitors, the linearly divided scale was fitted. The output voltage from the conductivity cell was measured over the two ranges and compared with the output from the balance circuit, the latter was corrected for deviation from the relationship required by adjusting the values of c_s and c_v by means of the trimming capacitors. It was also necessary to set the potentiometer P_1 to offset the small difference in efficiency between the rectifier and low-pass filter circuits, this enabled the ranges covered to fit those marked on the dial; the degree of linearity obtainable can be seen from Figs. 4 and 5.

The same procedure was used for adjusting and calibrating the temperature bridge. In this instance the required temperatures were obtained from a salt solution filtering through melting ice before passing over the thermometer bulb; a second thermometer being set in the T-junction as a standard. The output voltage relation was plotted against that for the balance circuit, the latter being adjusted until it too gave a similar curve. Finally P_2 was adjusted to off-set the difference in efficiency between the rectifiers.

3(*c*). *Computation of salinity.* The relationship between conductivity and the salinity and temperature of sea water is known accurately and a nomogram (Fig. 6) was constructed from published data.(3) This nomogram was derived from sets of intersections obtained from parallel scales of conductivity and temperature. The nomogram is accurate to within ±0·1 p.p.t. over salinities from 35 to 8 p.p.t. and within ±0·2 p.p.t. at 2 p.p.t. The accuracy of the instrument is better than ±0·3 p.p.t. over the salinity range covered.

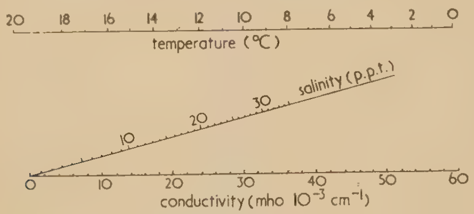


Fig. 6. Nomogram derived from conductivity and temperature tables

ACKNOWLEDGEMENTS

This article is published by permission of the Director of the Hydraulics Research Station. Acknowledgements are due also to Mr. G. L. J. Webb, who devised the nomogram, and Mr. J. P. Gale who carried out much of the development work.

REFERENCES

(1) Blake, G. G. *Conductimetric Analysis at Radio Frequency* (London: Chapman and Hall Ltd., 1950).
(2) McCourt. *J. Sci. Instrum.*, **30**, p. 241 (1953).
(3) Thomas, B. D. *Electrical Conductivity of Sea-water. J. Ass. Inst. Expl. de la Mer.*, **9**, pp. 28–35 (1934).

APPENDIX 1

The copper electrodes attached to the thermometer and conductivity tube were built on to the glass by an electroplating technique. The base used was a coating of liquid burnish silver, an emulsion of silver oxide and oils obtainable from Johnson and Matthey and Co. Ltd. The emulsion painted over the surface and heated to the annealing temp ture of the glass. This left a firm coating of silver on glass which was used as a base for electroplating. Be plating, the silver coating was washed in benzene to rem all grease. In the electroplating bath the tube was mou coaxially inside a cylindrical copper anode. The cur density was 16 A/ft^2 and the electrolyte used was cop sulphate (160 g/l.) and sulphuric acid (40 g/l.).

APPENDIX 2

The conductivity cell and balancing circuit are arrange the form of a bridge in which the functions of resistance capacitance are interchanged. It is required to show that bridge is balanced when:

$$\left.\begin{aligned} 1/(2\pi f C_v) &= K R_v &&= KV \\ 1/(2\pi f C_s) &= K R_s &&= KS \\ R_p &= K\,1/(2\pi f C_p) &&= KP \\ R_c &= K\,1/(2\pi f C_c) &&= KC \end{aligned}\right\}$$

The germanium rectifiers are in opposition, the detec i.e. the d.c. amplifier, being connected to the centre-tap resistance R_d in Fig. 3(*c*). Neither the d.c. amplifier nor rectifiers consume any significant current, therefore voltage at the detector is given by:

$$V_d = \frac{|V_{01}| - |V_{02}|}{2}$$

at balance $\qquad V_d = 0$

and $\qquad |V_{01}| = |V_{02}|$

Consider one side of a bridge having impedances as show Fig. 3(*d*)

$$\frac{V_{out}}{V_{in}} = \frac{p(c+v)}{p+c+v} \bigg/ \left[s + \frac{p(c+v)}{p+c+v}\right] = \frac{p(c+v)}{s(p+c+v)+p(c+}$$

for the cell: $p = -jP$, $c = -jC$, $v = V$, $s = S$ for balance circuit: $p = KP$, $c = KC$, $v = -jKV$, $s = -$ substituting in equation (4):

$$\frac{V_{01}}{V_i} = \frac{-jP(V - jC)}{SV - PC - j(SP + SC + PV)}$$

$$\frac{V_{02}}{V_i} = \frac{P(C - jV)}{-SV + PC - j(SP + SC + PV)}$$

It is obvious by inspection of equations (5) and (6) $|V_{01}| = |V_{02}|$ and thus the bridge is balanced if the condit in (1) are satisfied.

A fast coincidence system for the measurement of short lifetimes

By G. Jones, M.A.,* and Prof. J. B. Warren, Ph.D., F.Inst.P., Physics Department,
University of British Columbia, Vancouver, Canada

[*Paper received* 1 *June*, 1956]

Details are given of a fast coincidence system comparable to that developed by Bell, Graham and Petch⁽¹⁾ but employing the scheme of Neilson and James⁽²⁾ in which the time separation of associated events is converted to pulse amplitude and sorted on a conventional kicksorter. In this manner the whole coincidence resolution curve is obtained at one time while retaining an inherent time resolution of about 2 × 10^{-10} s.

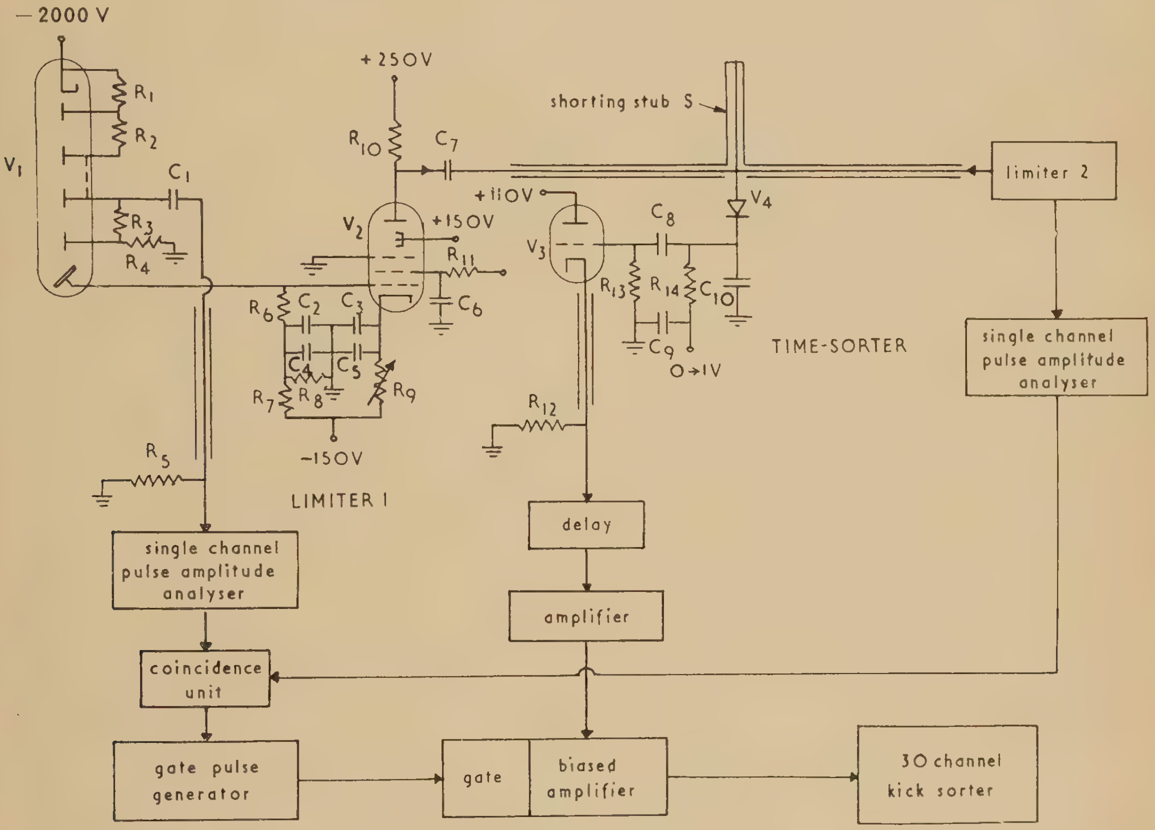

− 2000 V
V1
R1
R2
C1
R3
R4
R5
+ 250V
R10
C7
shorting stub S
limiter 2
+110V
V4
V2
+150V
R11
C8
V3
R6
C2
C3
C6
R13
R14
C10
C4
C5
R9
R7
R8
C9
O→IV
TIME-SORTER
single channel pulse amplitude analyser
R12
−150V
LIMITER I
delay
single channel pulse amplitude analyser
amplifier
coincidence unit
gate pulse generator
gate
biased amplifier
30 channel kick sorter

Fig. 1. Circuit of fast time sorter

R_1 = 480 kΩ
R_2–R_4 = 330 kΩ
R_5 = 100 Ω
R_6 = 10 kΩ
R_7 = 30 kΩ
R_8 = 50 kΩ
R_9 = 25 kΩ

R_{10} = 100 Ω
R_{11} = 82 kΩ
R_{12} = 100 Ω
R_{13} = 1·5 kΩ
R_{14} = 15 kΩ

C_1 = 200 pF

C_2, C_3 = 0·01 μF
C_4 = 8 μF
C_5 = 0·5 μF
C_6, C_7 = 0·01 μF
C_8 = 0·001 μF
C_9 = 0·01 μF
C_{10} = C integrating (25 pF + 10 pF stray capacity)

V_1 = 1P21
V_2 = VX5038
V_3 = 417A
V_4 = IN56

he technique for the measurement of short (approximately 0^{-9} s) lifetimes with the fast delayed coincidence equipment f the style developed by Bell, Graham and Petch⁽¹⁾ entails e point by point measurement of coincidence resolution urves for both the source under investigation and a prompt ource. This process requires quite a considerable time and emands very great stability in the apparatus.

Neilson and James⁽²⁾ in this laboratory developed a circuit sing a type 6BN6 gated beam tube in which the amplitude of the output pulse from the coincidence mixer is proportional, within a limited range, to the time of separation of the ingoing pulses. In this manner, by feeding the output pulses into a pulse height analyser, the associated events are time-sorted and it is possible to record the complete coincidence resolution curve at one time. While it is possible to achieve resolving times of the order of 10^{-9} s with the gated beam tube circuit, it is difficult to obtain any significant improvement since the type 6BN6 tube requires relatively large input pulses for proper operation. This necessitates the use of higher gain and extra tubes in the limiters resulting in a decrease in the available bandwidth.

---

* Now at Chalk River Laboratories, Atomic Energy of Canada td.

This problem has, to some extent, been circumvented in the system described below by using a germanium diode for the coincidence detector, which operates with signal pulses of a lower level than the type 6BN6, and time-sorting in essentially the same manner as Neilson and James.(2) The inherent resolution of the resulting system was found to be comparable to that of the circuit of Bell and others(1) and has been found useful in measuring time intervals in the 10^{-10} s range. The time to perform the experiment is much reduced, providing more freedom from the effects of slow gain shifts in the apparatus, and facilitating the use of weaker radioactive sources. Moreover, the resulting coincidence resolution curve is, of course, insensitive to the decay of the source.

THE FAST TIME-SORTER CIRCUIT

The circuit diagram of the time-sorter is shown in Fig. 1, only that portion of the circuit which involves fast pulses being shown in detail. The slow portions are indicated by block diagrams and are of conventional design. The radiation detectors were crystal blocks of diphenylacetylene, $1 \times \frac{3}{8} \times \frac{3}{8}$ in., mounted on type 1P21 photomultipliers, which were operated at around 2 100 V to ensure short transit time spreads. The operation of the type VX5038 limiters and associated circuits is similar to that described by Neilson and James and by Bell and others.

The time sorting is performed by the biased germanium diode followed by an integrating capacitor. Upon detection of coincident, or nearly coincident, γ-rays both limiters produce rectangular pulses of uniform amplitude clipped by the shorting stub to a duration of 5 mμs. A portion of the resulting potential wave form at the diode will have an amplitude twice that of a single pulse. Ideally, if the bias of the diode is adjusted to be equal to the amplitude of the single pulse, then conduction through the crystal will only occur during that time in which the two 5 mμs pulses overlap in time, as indicated in Fig. 2. The current passed by the diode is then integrated by the following capacitor, producing a voltage pulse, the amplitude of which is related to the overlap in time of the incident pulses. The diode also serves as a pulse stretcher, isolating the charge on the condenser from the rest of the circuit when the overlap portion of incident wave form disappears, so relatively slow ampli may be used following the time-sorter.

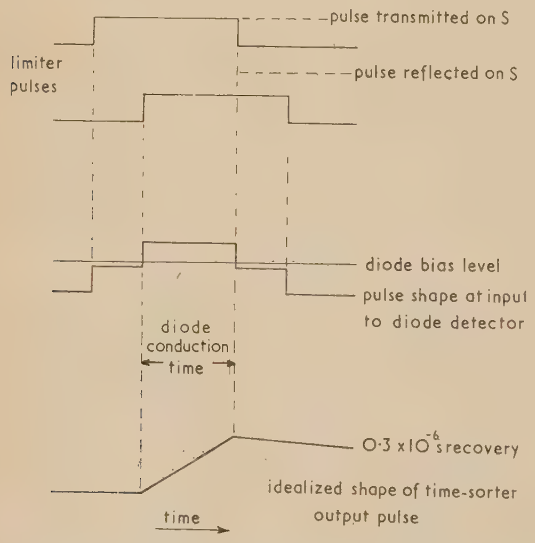


Fig. 2. Idealized wave forms of time sorter

A detailed analysis of the operation of the time-sort complicated by the loading imposed by the conducting di and by such effects as carrier transit time and hole sto in the germanium. As shown by the experimental res these effects do not prevent the use of this circuit at s resolving times; their main effects are a reduction in amplitude of the outgoing voltage pulses and a depar from linearity between the output pulse size and the tim overlap of the ingoing pulses.

The stability of the time-sorter was considerably impro by placing the whole instrument in a thermally insula box, made of polystyrene foam, and controlling the t perature of the enclosure. Since the characteristics of germanium diode are quite sensitive to temperature, c was taken to ensure that the temperature of this compon changed as little as possible.

Since both amplitude and rise time of the output pu from the scintillation counters are strongly dependent on energy expended in the scintillator by the ionizing radiati the pulses introduced to the time sorter by the limiters not absolutely uniform in shape. Variations in rise time the coincident limiter output pulses produce a jitter in overlap time of the pulses at the time-sorter input, wh broadens the measured coincidence resolution curve. Co quently side channel amplitude selection with subsequ gating of the fast channel was employed to ensure tha observed pulse distribution spectrum resulted from co cidences between approximately uniform pulses. An ad advantage in using side-channel pulse height analysers the ability to make some discrimination as to the energy the γ-rays producing the ionization, by setting the "windo in the pulse height discriminators to view the appropr part of the Compton spectrum.

The outputs of the side-channel analysers were fed int slow coincident unit of 1 μs resolving time which, in tu operated a linear gate through which the amplified tin sorter pulses passed before being displayed on a thi channel kicksorter.

PERFORMANCE

Since the resolution time is dependent on the window wi of the side-channel analysers, very narrow resolution cur could only be obtained at the expense of coincidence count rate and a compromise was necessary. A 0·002 mc sou of ^{76}As was used to test the performance. According Kurbatov, Murray and Sakai(3) the γ-radiation from t substance contains 2·05 and 0·55 MeV components cascade, while the lifetime of the 0·55 MeV state in ^{76}Se about $1{\cdot}5 \times 10^{-11}$ s,(4) a value much below the resolvi time of this apparatus. Consequently these two γ-rays m be taken as coincident in time.

With this source and a coincidence counting rate of f per minute, the prompt coincidence resolving curve shown Fig. 3 was obtained, which has a full width at half maximu of $8{\cdot}3 \times 10^{-10}$ s. The coincidence rate drops by a fact of two in $1{\cdot}9 \times 10^{-10}$ s, from the left-hand side of the cur and in $2{\cdot}3 \times 10^{-10}$ s from the right-hand side, indicati that the inherent resolution of the apparatus is compara to that obtained by Bell and others and is limited primar by the scintillation counters.

The overall stability was checked by repeatedly measurin coincidence resolution curve during the course of a da ver this period the mean of a coincidence resolving curve ould be reproduced to within a tenth of a kicksorter channel idth, i.e. about $0{\cdot}2 \times 10^{-10}$ s, with a certainty of 80%.

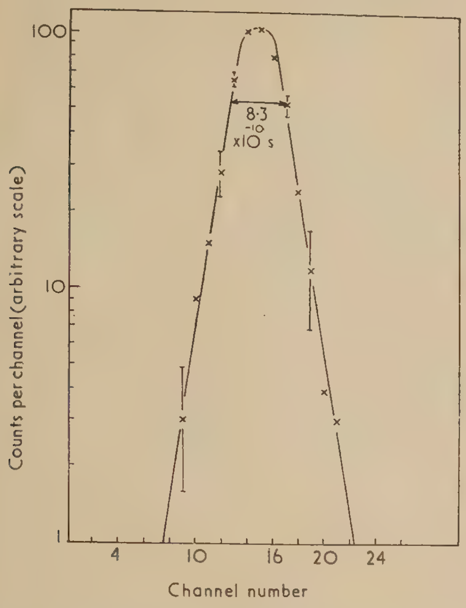


Fig. 3. Prompt coincidence resolution curve taken with ^{76}As source. The time calibration is $1{\cdot}9 \times 10^{-10}$ s per channel

There are two disadvantages to this technique. The first the non-linearity of the time scale. However, it is possible determine the operating characteristics of the time-sorter ich that the portion of the time calibration curve of most terest may be approximated quite closely by a straight ne. In Fig. 4 is shown a calibration curve obtained by

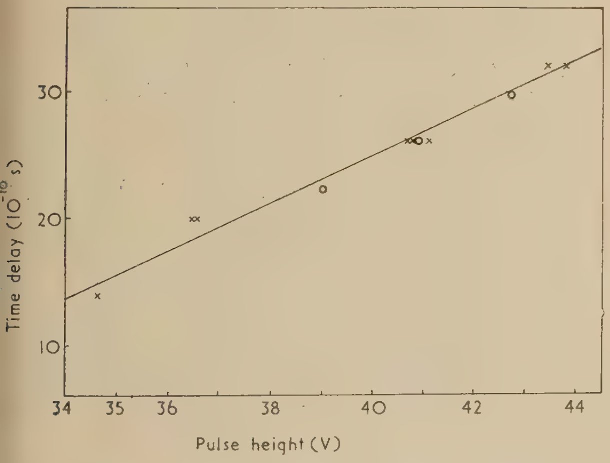


Fig. 4. Pulse height/time calibration curve

easuring the shift of the peak of the coincidence resolving irve as a function of inserted delay in one of the channels. A similar plot is obtained by varying the distance of one of the counters to the source and evaluating the γ-ray time of flight. The slope of the straight line drawn in Fig. 4 is $1{\cdot}8 \times 10^{-10}$ s/V.

There is also a small dependence of the output pulse height on the counting rate, which must be taken into account when comparing sources of widely different activities. This was measured by altering the distance between the source and both counters keeping the γ-ray path length equal for both counters. The resulting plot of the position of the centroids of the coincidence resolving curves against coincidence counting rate is shown in Fig. 5, the open and closed points representing measurements made a month apart. The dependence of pulse height on counting rate may be closely approximated by a straight line for this range of counting rates.

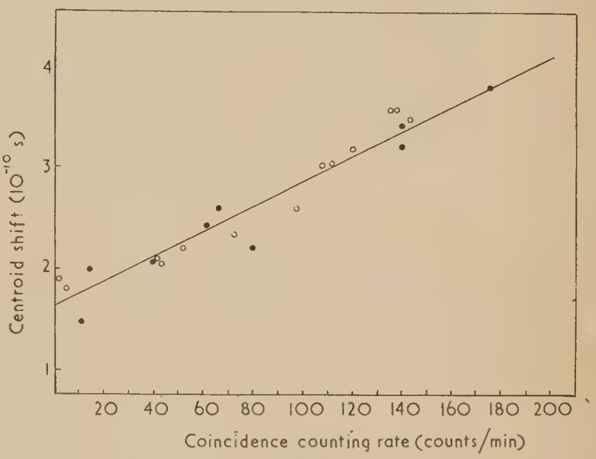


Fig. 5. Dependence of pulse height from time-sorter on coincidence counting rate

ACKNOWLEDGEMENTS

One of us (G.J.) gratefully acknowledges the award of a National Research Council Bursary during the tenure of which the equipment was built. We are indebted to Dr. K. Erdman for preparing the ^{76}As source and for much helpful assistance.

REFERENCES

(1) BELL, R. E., GRAHAM, R. L., and PETCH, H. E. *Canad. J. Phys.*, **30**, p. 35 (1952).

(2) NEILSON, G. C., and JAMES, D. B. *Rev. Sci. Instrum.*, **26**, p. 1018 (1955).

(3) KURBATOV, J. D., MURRAY, B. B., and SAKAI, M. *Phys. Rev.*, **98**, p. 674 (1955).

(4) TEMMER, G. M., and HEYDENBURG, N. P. *Phys. Rev.*, **100**, p. 961 (1955).

Dynamometer for tensile testing of high polymers

By A. R. Payne, B.Sc., Grad.Inst.P., and J. F. Smith, B.Sc., Ph.D., A.R.I.C., Research Association of British
Rubber Manufacturers, Shawbury, Shrewsbury, Shropshire

[*Paper first received* 23 *March, and in final form* 30 *May*, 1956]

The instrument described in this paper for measuring static and dynamic stresses is a new type of dynamometer that has been found useful, especially in tensile testing of high polymers. This dynamometer measures force by the deformation of a proof ring. Load range and sensitivity can be changed instantaneously by adjusting an attenuator in the electronic circuit; this obviates the necessity for stopping the test and changing the pendulum weight of the conventional test machine, and also gives a much greater range of loads. A fine gain control on the amplifier driving the recorder can be calibrated in terms of specimen thickness, which in conjunction with special scales for use on the recorder chart, makes the instrument record stresses directly in pounds per square inch.

Frictional and inertia effects, which occur only in the recorder, are considerably reduced, and if a cathode ray-oscillograph is used instead of the recorder, friction and inertia are virtually eliminated and rapid force changes can be followed.

The new dynamometer is robust in design, linear in response to force, and easily adaptable to all present-day types of rubber tensile testing machine. Preliminary tests show that the new instrument gives more reproducible results in tensile tests on rubber than do pendulum machines.

Physical tests in which specimens, usually of dumb-bell form, are subjected to tension stresses have been widely used to determine the quality of rubber and plastics products. So wide is this use that nearly all specifications for elastomeric products contain requirements for tensile strength and breaking elongation, and sometimes for modulus at various elongations.

The machines generally used in tensile testing of rubbers employ a dynamometer of the pendulum type and hence are subject to errors of load indication due to inertia, momentum effects, and friction in the bearings supporting the pendulum. Inertia and momentum alone contribute so much error that values within the lower 15% and upper 15% of the load range of a pendulum type dynamometer are not considered valid.(1)

Other defects are the friction in the associated autographic system which is actuated by the movement of the pendulum; moreover, because of mechanical limitations, a change of load range necessitates changing the weights attached to the pendulum, and, in general, the tensile machines of the pendulum type are of low sensitivity.

Recently, an electronic type of dynamometer and recording system, using a mechanical-electrical transducer, has been developed in America by James and Morris.(2) It employs unbonded strain-gauge elements in a bridge circuit, but this method, although free from friction and inertia, suffers from lack of sensitivity and adaptability because of the limitations of the strain gauges involved.

GENERAL DESCRIPTION OF THE DYNAMOMETER

The new dynamometer head discussed in this paper comprises a proof ring and an induction displacement pick-up (Philips type GM 5537) attached to a conventional tensile tester (Hounsfield rubber testing machine). The force dynamometer head attached to the tester is shown in Fig. 1.

The pick-up is a differential transformer working on a 4 kc/s signal fed into a bridge network, the resulting signal from the bridge being amplified and recorded. Fig. 2 is a block diagram of the electronic circuit.

Force dynamometer proof ring. The proof ring section of the dynamometer was cut from a solid oblong of mild steel. The machining necessitated cutting a slit and two circular sections as shown in Fig. 3. A commercial differential transformer, Philips type GM 5537, was fitted so that the probe bears on one face of the slit. The outer side fac the proof ring were not rounded in section as in a conventi proof ring, but made octagonal, for three reasons: for e of machining; to be rigid and stiff; and to enable the sensiti

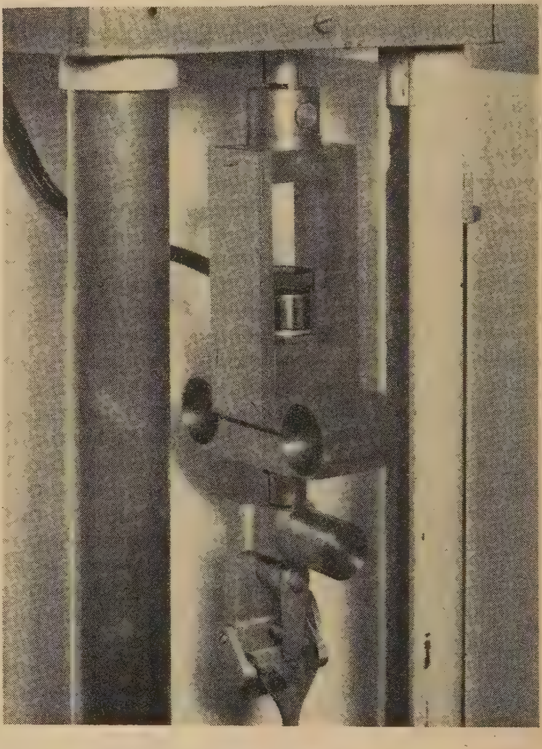


Fig. 1. Dynamometer head attached to a conventiona tensile tester

of the proof ring to be easily adjustable by filing down th edges. The shape of the outer end section is of little imp tance and the octagonal section does not impair the lin force-displacement properties of the proof ring.

Displacement pick-up and bridge. The pick-up is based the principle of variable coupling. A small core of Ferr cube attached to the probe of the pick-up moves to and a non-magnetic tube on which three small coils are wound. e pick-up probe protrudes through the steel case and is ached to two special thin leaf springs. The middle primary l is energized with a carrier wave voltage drawn from the asuring bridge and induces in the other two (secondary) ils a voltage which depends upon the position of the iron re and thus of the probe.

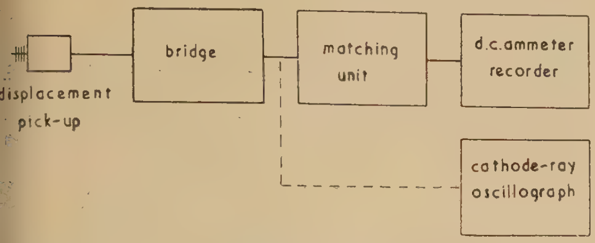


Fig. 2. Block diagram of the electronic circuit

The pick-up was connected to a section of a Philips type M 5536 bridge and use was made of (1) the bridge circuit th capacitative elements for zero adjustment with respect amplitude and phase prior to taking measurements; the stable four-stage amplifier of high sensitivity for nplifying the bridge voltage, the amplification being adjusted a calibrated attenuator; (3) the oscillator for feeding the idge circuit; and (4) the output circuit for connexion to a corder or cathode-ray oscillograph. With the aid of the tenuator, six displacement ranges were available, namely, $3\,\mu$, $\pm 10\,\mu$, $\pm 30\,\mu$, $\pm 0{\cdot}1$ mm, $\pm 0{\cdot}3$ mm, and $\pm 1{\cdot}0$ mm, spectively, about the null point. In the most sensitive nge, that of $\pm 3\,\mu$, one scale division is $0{\cdot}1\,\mu$.

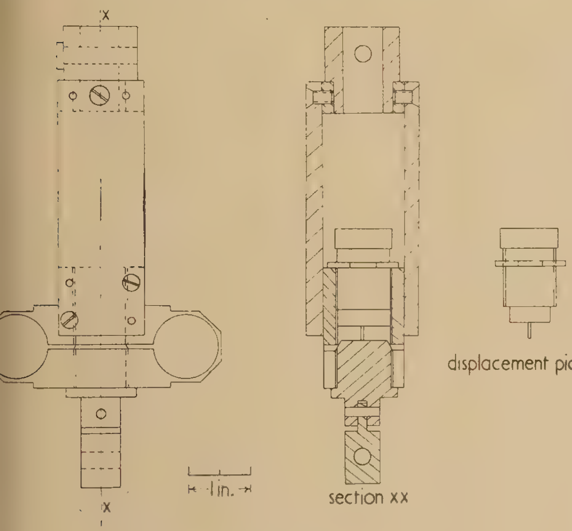


Fig. 3. Dynamometer proof ring

Matching unit and recorder. The bridge was not capable driving a normal pen recorder directly so a matching unit sed on the ring modulator principle was constructed. A ng modulator circuit is one in which the rectifiers (or nducting paths) are arranged in a ring.(3) The electronic cuit is shown in Fig. 4. The "switching" voltage for the ng modulator is obtained from the Philips bridge and nplified by valves V_1 and V_2; condenser C_0 together with the variable condensers and phase checking devices in the Philips bridge balance out any phase shift produced by this amplification. The "signal" voltage to the ring modulator is first increased by a factor of 2 by transformer T_1, with a push-pull output. The precision stud attenuator R_{14} and the fine gain control R_{13} are incorporated at this stage. The output of this attenuator is amplified by valves V_3 and V_4 in class A push-pull, the output voltage is delivered to the ring modulator *via* transformer T_3 and then used to drive a recording d.c. ammeter G (Murday system by Evershed and Vignoles Ltd.). The conventional full-wave arrangement for demodulation was not used because for some applications of the dynamometer (not discussed in this paper) it was necessary to distinguish between compression and tension. Wave-form distortion associated with half-wave rectification does not, as far as can be ascertained, effect the calibration of the system.

The fine gain control R_{13} is calibrated in specimen thickness, and makes the output to the recorder proportional to this thickness, so that the recorder chart can be calibrated directly in pounds per square inch.

PERFORMANCE

Load range. This depends on the dimensions of the proof ring used, but the following is a typical example: 200 g when the bridge is set to the most sensitive range ($3\,\mu$), 66·6 kg in the least sensitive range (1 mm).

Thus with one proof ring a load range of 333 : 1 can be covered. This compares very favourably with the most versatile type of pendulum testing machine which provides a full-scale load range of about 16 : 1.

Sensitivity. It is in respect of sensitivity that the present instrument excels in comparison with other rubber testing machines. Thus, with the most sensitive proof ring that the authors have used, a full-scale deflexion of 4 in. for 200 g was obtainable, enabling a load of 5 g to be easily measurable, compared with 250 g on the normal rubber testing machine.

Linearity. The present instrument is linear in response with respect to load to within $2{\cdot}5\%$, over the whole scale. Only radio quality transformers and rectifiers have been used in the recorder matching unit, and better performance could no doubt be obtained by using better components. However, the pen recorder is limited in accuracy to within $2\frac{1}{2}\%$, and the overall performance is thus as good as the recorder allows; any non-linearity can be compensated for by the ruling of the Perspex scales used in reading the charts.

Stability. After an initial warming-up period the instrument shows no drift over a period of six hours either in deflexion due to constant load or in the bridge zero.

Temperature coefficient. The pick-up can withstand temperatures up to 70° C. The proof ring alters its dimensions appreciably with change of temperature, but at any constant temperature this has no effect, because when setting the bridge to zero it is adjusted to compensate for any change in the dimensions of the proof ring. The only practical effect of temperature is that owing to the change in dimensions of the displacement pick-up pin; a 10° C temperature change produces 1% change in sensitivity.

Force displacement ratio. This varies with the dimensions of the proof ring, but in the most sensitive ring used it was of the order of 100 g/μ compared with $0{\cdot}04$ g/μ on conventional

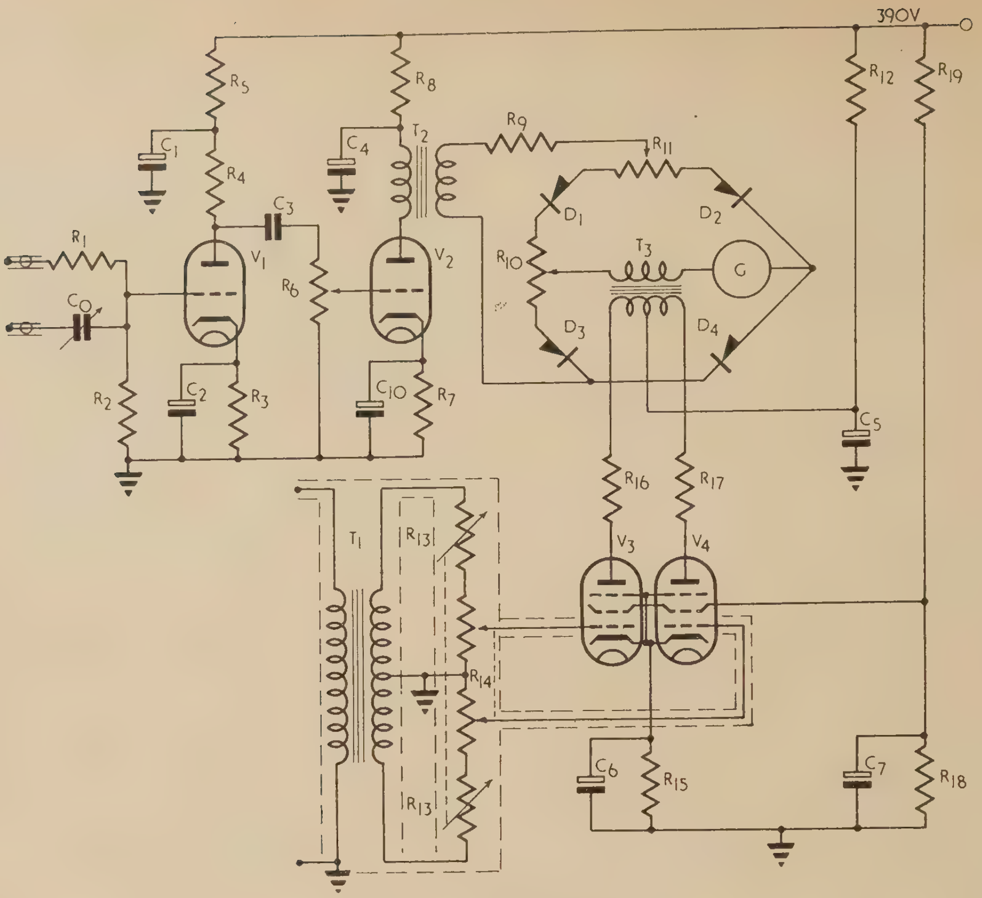


Fig. 4. Matching unit

All resistors are ½ W, except where indicated.

R_1 = 0·47 MΩ
R_2 = 4·7 MΩ
R_3 = 1 kΩ
R_4 = 50 kΩ, 4 W
R_5 = 10 kΩ, 2 W
R_6 = 100 kΩ potentiometer
R_7 = 1 kΩ
R_8 = 15 kΩ, 2 W
R_9 = 4·7 kΩ
R_{10}, R_{11} = 5 kΩ potentiometer
R_{12} = 6·3 kΩ, 4 W

R_{13} = twin gang variable total 75 kΩ each limb
R_{14} = twin-stud attenuator, to give 5 : 1 range of sensitivity total 250 kΩ each limb
R_{15} = 69 Ω
R_{16}, R_{17} = 4·7 kΩ, 1 W
R_{18} = 20 kΩ, 2 W
R_{19} = 18 kΩ, 2 W

C_0 = trimmer 3–28 μF
C_1 = 8 μF, 450 V electrolytic
C_2 = 25 μF, 50 V electrolytic

C_3 = 0·05 μF, 500 V
C_4, C_5 = 8 μF, 450 V electrolytic
C_6 = 250 μF, 25 V electrolytic
C_7 = 8 μF, 450 V electrolytic
C_{10} = 25 μF, 25 V electrolytic

V_1, V_2 = 6J5
V_3, V_4 = SP61

T_1 = 2 : 1 step-up input transformer to match 10 kΩ primary impedance push-pull output; Mumetal screened; by Parmeko Ltd.

T_2 = 10 kΩ : 10 kΩ matched outpu transformer, 1 W primary d.c current 10 mA; by Parmek Ltd.
T_3 = 200 kΩ : 5 kΩ push-pull outpu transformer 1 W by Parmek Ltd.

G = recorder

D_1–D_4 = Senter cell M.3

pendulum machines. This high force/displacement ratio, although of little consequence in normal elastomer testing, is highly desirable for small dynamic stressing and straining. No exact information is available concerning the ratio attainable with strain gauges, but in the load range concerned it was much lower than with the present instrument.

APPLICATION

The instrument is applicable to ordinary rubber and plastic tensile and modulus tests and can be fitted to all standard testing machines by simple adaptors. The high sensitivity enables accurate tests to be made on thin films. It is particularly suited to stripping tests on adhesives, especially when the stripping speed is very low, as it obviates the need for frequent readings. The instrument is applicable to tyre cord adhesion testing provided the speed of "pull-through" is not too great in comparison with the response time of the recorder, which, however, is more rapid than with the normal pendulum system.

Chart recordings of a typical stripping test on an adhes a tensile test, and a tyre cord adhesion test are show Fig. 5.

Comparisons with a conventional tester. A compari between the electronic and a pendulum dynamometer of conventional type, was carried out. When the results of tensile tests and the times taken to complete tests compared, it was found that the electronic dynamom results for modulus were significantly higher for the so rubbers at low elongations than those of the pendu dynamometer, although the results were comparable for higher elongations of the softer and at all elongations of harder rubbers; results for tensile strength and break elongation were also comparable.

There was a considerable reduction in the time of test on the electronic dynamometer as compared with a c ventional pendulum machine. The two dynamometers w compared by simultaneous measurements on the same du bell testpiece. This comparison is awaiting publication.

This dynamometer has the special advantage in that l ge and sensitivity can be changed instantaneously by justing the attenuator in the electronic circuit; this obviates necessity for stopping the test and changing the pendulum ight as would be necessary with the conventional test achine, and also gives a greater range of available loads. is enables the initial part of the stress-strain curve of a ft material to be as accurately recorded as the complete ess-strain curve. A typical curve illustrating the full use the range and sensitivity control on a conventional rubber nsile test is shown in Fig. 6.

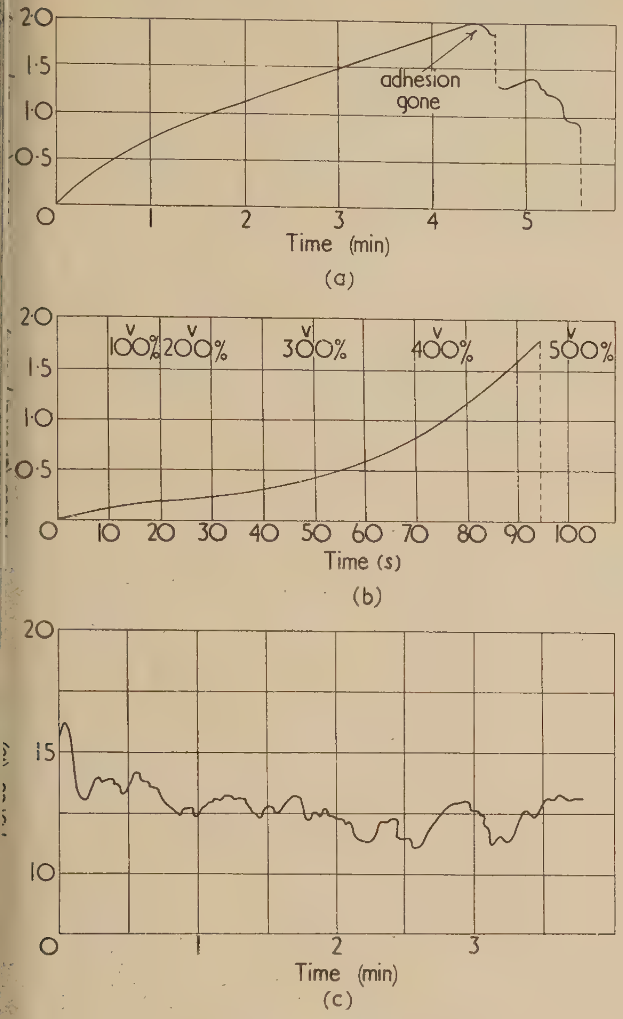


Fig. 5. (*a*) A typical "pull-through" adhesion test. (*b*) A typical tensile test. (*c*) Stripping test (speed of strip 0·085 in./min)

This dynamometer can be used in conjunction with an electrical extensometer,$^{(4)}$ which measures the strain on elastometer test pieces, thus allowing the recorded stress-strain curve to be completely autographic; this is of particular value for plastics, where the problem of suitable extensometers is not so difficult as with rubbers.

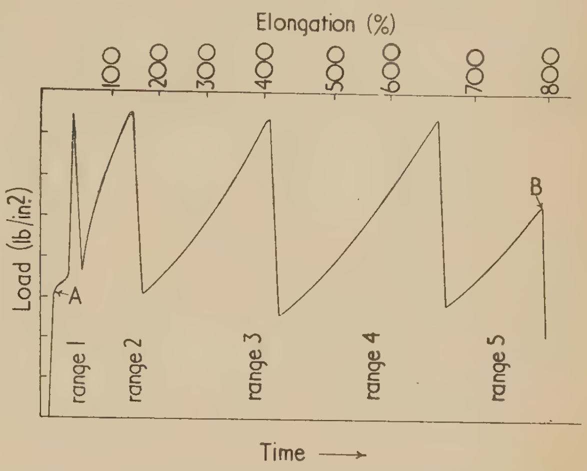


Fig. 6. Typical tensile test for rubber, making use of the change of load range during test. *A*, initial reaction of rubber dumb-bell in the tensile tester grips; *B*, dumb-bell broken. Time to break approximately twenty seconds

ACKNOWLEDGEMENTS

The authors thank Philips Electrical Ltd. for permission to publish a few details of their bridge type GM 5536 and the inductive displacement pick-up type GM 5537; Parmeko Ltd. for supplying the special transformers T_1, T_2 and T_3 required in the amplifier; and their colleague Mr. D. G. Lamb for helpful discussion on the proof ring.

REFERENCES

(1) *Tension Testing of Vulcanised Rubber*, D412-51T (American Society for Testing Materials, 1954); *Brit. Stand.* 903 (1950).

(2) James, R. R., and Morris, R. E. *Rubber World*, **131**, p. 635 (1955).

(3) Terman, F. E. *Radio Engineers Handbook*, p. 553 (New York: McGraw-Hill Publishing Co. Ltd., 1950).

(4) Klute, C. H., Panther, C. J., and McKee, L. B. *Amer. Soc. Test. Mat. Bull.* No. 180 (T.P. 40) (1952).

An electronic analogue of the saturated vapour pressure curve of water

By R. J. TAYLOR, B.Sc., A.Inst.P., Division of Meteorological Physics, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia

[*Paper first received* 23 *April, and in final form* 24 *July*, 1956]

An analogue of the saturated vapour pressure curve of water between 0 and 30° C which is suitable for inclusion in a complete electrical simulation of the psychrometric equation is described. The stated range of temperature can be covered in three sub-ranges of ten centigrade degrees, each with an accuracy in vapour pressure of a fraction of 1%. A theoretical analysis indicates that the slope of the curve, which is important in certain applications, is reproduced with 2% accuracy.

In the development of equipment to measure evaporation from natural surfaces, the need became apparent for a linear hygrometer of good accuracy and rapid response. Since wet-bulb resistance thermometers with time-constants of a fraction of a second have been developed,(1) an obvious approach is by way of the psychrometric equation

$$e = e_s - A(T_D - T_W) \qquad (1)$$

where e is the vapour pressure, e_s is the saturated vapour pressure at wet-bulb temperature, T_D and T_W are the dry- and wet-bulb temperatures and A is a constant involving the total air pressure.

Circuits have been devised (e.g. by Swinbank(2)) which make use of a straight-line approximation to a segment of the (e_s, T_W) curve. This is accurate enough if the variations which occur in e_s do not exceed one or two millibars, but the equipment now being designed will be required to run without adjustment for periods of some hours so that larger variations in e_s are to be expected. More accurate linearization of the (e_s, T_W) curve is therefore necessary.

The measurement of evaporation requires the determination of the covariance between specific humidity and the product of air density and vertical component of wind velocity. In the design of the hygrometer, therefore, the main emphasis must be on its ability to measure accurately relatively small variations from a central value which is, itself, of little importance. Consequently, in judging the goodness of fit of any empirical approximation to the (e_s, T_W) curve, the percentage error in slope is a more appropriate (and much more stringent) test than the percentage error in e_s. However, the central value from which excursions are measured must possess the same stability as if absolute values of e_s were required, and to adapt the instrument to this latter purpose would merely require the addition of a known constant.

DESIGN

Calculation shows that a Wheatstone bridge, one arm of which is a wet-bulb thermometer, will give a good approximation to a segment of the (e_s, T_W) curve if provided with feedback which is positive when T_W is greater than the tem ture at which the bridge is balanced. In Fig. 1, if E_0 constant input voltage, k is a constant depending on bridge characteristics, a is the temperature at which bridge is balanced, μ is the gain of the feedback amp and x is the output, then it can be shown that

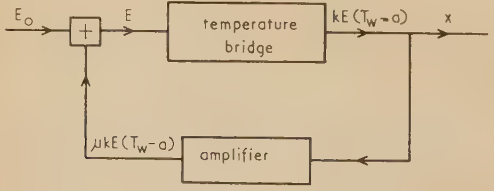


Fig. 1. Block diagram of feedback circuit

$$x = E_0 \frac{k(T_W - a)}{1 - \mu k(T_W - a)}$$

An arbitrary scale constant can, of course, always be a and we write:

$$x = C \frac{T_W - a}{1 - b(T_W - a)}$$

where C includes E_0, k and the scale factor and $b = \mu k$

How well the curve fits may be seen from the values in the table.* In no case does the error in slope att much as 2% and to convert values of x to absolute va pressures requires merely the addition of a constant 17·0 (e_s when $T_W = 15°$ C). It is clear that, if this were c the error in e_s would never exceed 0·03 mb or about 0

Comparison of slopes of saturated vapour pressure curve calculated output from analogue

T_W (°C)	e_s (mb)	δe_s (mb)	x (mb)	δx (mb)	$\frac{\delta x}{\delta e}$ (%
10	12·27	0·85	—4·77	0·86	1·
11	13·12	0·90	—3·91	0·90	0
12	14·02	0·95	—3·01	0·95	0
13	14·97	1·01	—2·06	1·00	1·
14	15·98	1·06	—1·06	1·06	0
15	17·04	1·13	0	1·12	0·
16	18·17	1·20	1·12	1·19	0·
17	19·37	1·26	2·31	1·25	0·
18	20·63	1·33	3·56	1·34	0·
19	21·96	1·41	4·90	1·43	1·
20	23·37		6·33		

A change in the value of C from one range of T_W to ano is clearly necessary because of the changing slope of (e_s, T_W) curve, the values for the ranges 0–10° C, 10–2 and 20–30° C being in the ratios 1 : 1·38 : 3·09. The for a change in b is not so apparent and, indeed, calcula gives $b = 0·0281$ for the range 10–20° C and a v $b = 0·0258$, a change of less than 10%, for the range 20–30 It can be shown that little accuracy is lost (except near nts in the 0–10° C range) if the constant value $b = 0{\cdot}0281$ sed throughout the whole range 0–30° C. This is con-ient in the practical design as it eliminates a ganged trol.

---

* All values of saturated vapour pressure quoted are taken f Organisation Meteorologische Internationale Publication No. Lausanne 1949, Aerological Commission.

PRACTICAL PERFORMANCE

The detailed circuit diagram is shown in Fig. 2. The put of the temperature-sensitive bridge is amplified by and V_2, and mixing to provide the necessary feedback is omplished by means of V_3 and the hybrid bridge. The ter has the temperature-sensitive bridge for one of its arms, e other three arms containing resistors R_{16} to R_{20}. A pping point on R_{22} controls the amount of feedback; to just this setting requires the use of a soldering-iron, but a itch is provided in conjunction with R_{22} by means of which e feedback can be removed altogether for convenience in rvicing. The output is shown on a microammeter after ase-sensitive detection in V_4.

A double-pole switch provides three positions for use in ting up the instrument. In the "hybrid balance" position, e only signal reaching V_4 is that which would result from ck of balance in the hybrid bridge. Balancing of this idge can then be achieved and reset from time to time, if cessary, by adjustment of R_{18}. The "cathode balance" sition earths the grids of V_4 and allows the balancing of e two halves of this valve by means of R_{30}. The position rked "linearizing" is the running position where the feedback is in operation and the output is a linear representation of saturated vapour pressure.

In the laboratory where the equipment was built and tested, the mains supply was frequently of bad waveform and it was necessary to ensure that the voltages reaching the plates and grids of the phase-sensitive detector V_4 should, as nearly as possible, suffer the same distortion so that changes in the mains waveform should not cause drifts. For this reason, the plates are supplied from a transformer with tuned secondary. For use where a constantly good mains waveform is assured, the mains voltage can be applied directly to the plates.

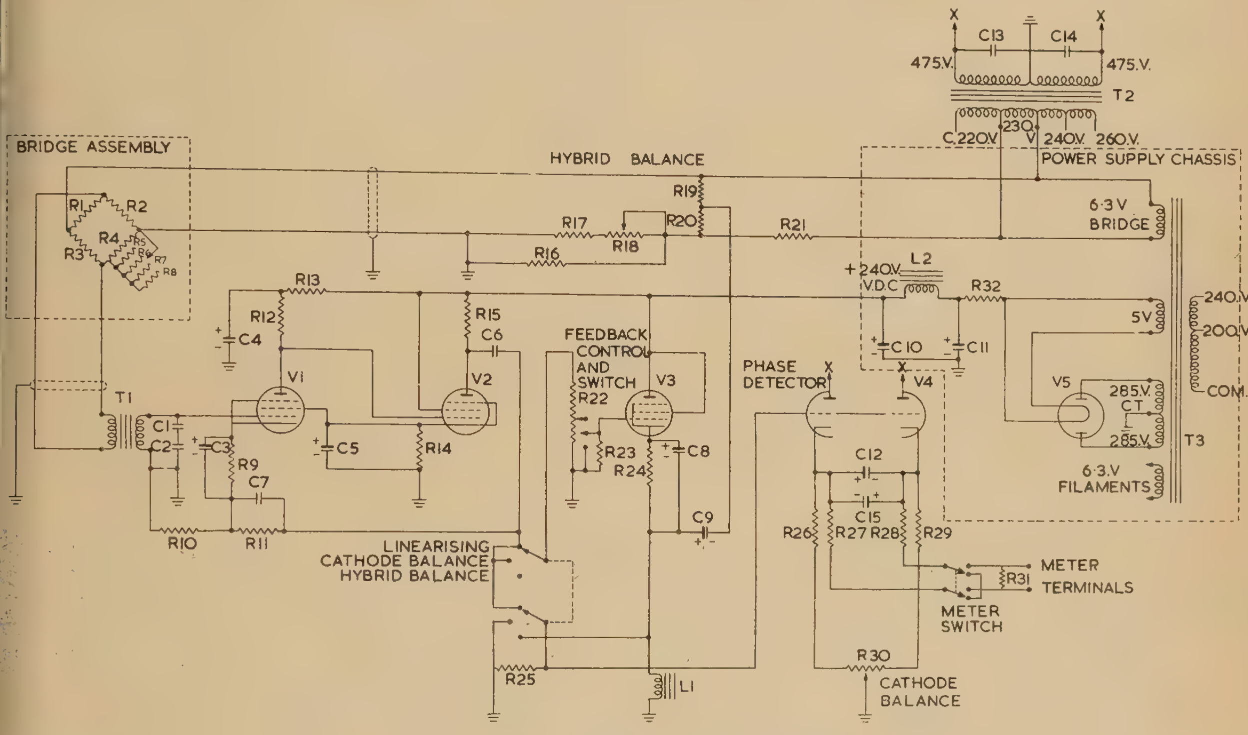

X
C13
C14
X
475.V.
475.V.
T2
230
C.220V.
240V.
260.V.
POWER SUPPLY CHASSIS
BRIDGE ASSEMBLY
HYBRID BALANCE
R19
R1
R2
R4
R5
R6
R7
R8
R3
R17
R20
R18
R16
R21
6·3 V
BRIDGE
+240V.
V.D.C
L2
R32
R13
R12
C4
R15
C6
FEEDBACK CONTROL AND SWITCH
R22
V3
V1
V2
PHASE DETECTOR
X
V4
C10
C11
240.V.
200.V.
5V
COM.
V5
285.V.
C.T.
285.V.
T3
T1
C1
C2
C3
C5
R14
R23
R24
C8
R9
C7
C12
C15
6·3.V
FILAMENTS
C9
R10
R11
LINEARISING
CATHODE BALANCE
HYBRID BALANCE
R26
R27
R28
R29
METER
TERMINALS
R31
METER SWITCH
R25
L1
R30
CATHODE BALANCE

Fig. 2. Circuit details of electronic analogue

$R_1 = 14{\cdot}1\ \Omega$
$R_2 = 96\ \Omega$
R_3 = thermometer
$R_4 = 96\ \Omega$
R_5–R_8 = adjusted to provide desired ranges
$R_9 = 4{\cdot}5\ \text{k}\Omega$
$R_{10} = 500\ \Omega$
$R_{11} = 10\ \text{k}\Omega$
$R_{12} = 2\ \text{M}\Omega$
$R_{13} = 100\ \text{k}\Omega$

$R_{14} = 2\ \text{k}\Omega$
$R_{15} = 10\ \text{k}\Omega$
$R_{16} = 100\ \Omega$
$R_{17} = 50\ \Omega$
$R_{18} = 100\ \Omega$
$R_{19}, R_{20} = 5\ \Omega$
$R_{21} = 7\ \Omega$
$R_{22} = 500\ \text{k}\Omega$
$R_{23} = 1\ \text{M}\Omega$
$R_{24} = 125\ \Omega$

$R_{25} = 470\ \text{k}\Omega$
$R_{26} = 10\ \text{k}\Omega$
$R_{27}, R_{28} = 5\ \text{k}\Omega$
$R_{29} = 10\ \text{k}\Omega$
$R_{30} = 500\ \Omega$
$R_{31} = 1\ \text{k}\Omega$
$R_{32} = 500\ \Omega$

$C_1, C_2 = 0{\cdot}1\ \mu\text{F}$
$C_3 = 50\ \mu\text{F}$

$C_4 = 8\ \mu\text{F}$
$C_5 = 50\ \mu\text{F}$
$C_6 = 1{\cdot}0\ \mu\text{F}$
$C_7 = 0{\cdot}1\ \mu\text{F}$
$C_8 = 50\ \mu\text{F}$
$C_9 = 100\ \mu\text{F}$
$C_{10}, C_{11} = 8\ \mu\text{F}$
$C_{12} = 50\ \mu\text{F}$
$C_{13}, C_{14} = 0{\cdot}1\ \mu\text{F}$
$C_{15} = 50\ \mu\text{F}$

V_1, V_2 = EF42
V_3 = EL41
V_4 = 6SN7GT
V_5 = 5Y3GT

L_1 = 14 H, 600 Ω
L_2 = 30 H

T_1 = microphone transformer 40 : 1
T_2, T_3 = suitable power transformers

Stability over periods of a few hours is good, the fluctuations in readings observed being of order $0{\cdot}25\ \mu$A even when the ambient temperature is changed by 12° C. These fluctuations correspond to voltage irregularities of about $2{\cdot}5$ mV at the cathodes of V_4 and, at sensitivities which will be used in practice, to vapour pressure fluctuations of less than $0{\cdot}02$ mb.

Calibration in a water bath using a resistance thermometer comprising $12{\cdot}35\ \Omega$ of copper at 0° C yielded the typical calibration shown in Fig. 3. The linearization is good but there is some scatter of points. In order to obtain this calibration, voltage division at the grids of V_4 was used to compress into the range of the meter a greater range of vapour pressure than will be needed in practice. The deviations of individual points from the line in Fig. 3 (about $\frac{1}{2}$ scale division, less than $0{\cdot}1$ mb) correspond to voltage fluctuations at the cathodes of V_4 of about 1 mV, and are thus of the same order as the fluctuations from time to time noted above. Moreover, the instrument will always be used in the field at such a sensitivity that the fluctuations actually occurring in the atmosphere at the time appear large on the meter, and so it is the slope over the whole range o meter which is of importance, rather than the slope o small part of it which is more subject to the effects of fluctuations.

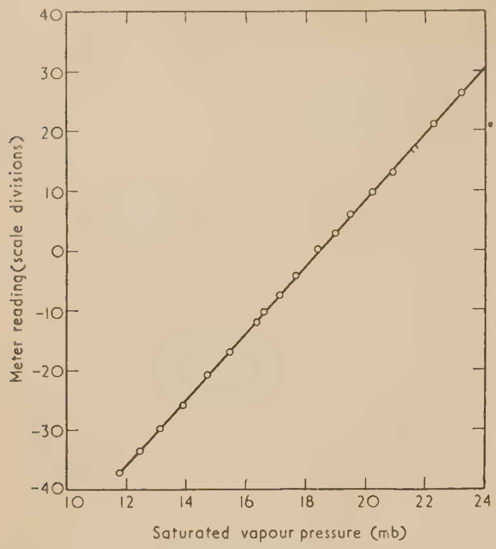


Fig. 3. Experimental verification of saturated vapour pressure analogue

After good linearity of the (x, e_s) graph was achiev rough measurement was made of the feedback factor equation (2)]. This lay within 9% of the calculated for the range, which was probably about the limit of accu of the measurement. The expected insensitivity of linearization to variations of order 10% in b was also firmed experimentally. These facts, together with the linearity exhibited in Fig. 3 are sufficient assurance equation (2) adequately describes the circuit behaviour.

The instrument described can form only a part hygrometer reading linearly in vapour pressure. How the complete electrical simulation of equation (1) requ in addition, only linear functions of observable quan which may readily be obtained by well-established techni of wet- and dry-bulb resistance thermometry.

ACKNOWLEDGEMENTS

The electronic circuit shown in Fig. 2 was designed built by Mr. R. R. McGregor. Mr. E. A. Cohen ca out much of the work of calibration.

REFERENCES

(1) McIlroy, I. C. *C.S.I.R.O., Div. Met. Phys. Tech.* No. 2 (1955).
(2) Swinbank, W. C. *J. Sci. Instrum.*, **28**, p. 86 (1951).

An all-glass reference electrode for molten salt systems

By J. O'M. Bockris, D.Sc.,* G. J. Hills, Ph.D., D. Inman, B.Sc., A.R.C.Sc., and L. Young, M.A., Ph.D.,†
Imperial College of Science and Technology, London, S.W.7

[*Paper received* 6 *July*, 1946]

The construction and performance is described of a glass electrode generally applicable to molten salt systems up to 550° C.

Several types of reference half-cell have recently been proposed(1–9) for use in molten salt systems. That used by Senderoff and Brenner,(1) Ag | molten AgCl | asbestos plug | . . . is simple to make and use but introduces an unknown and variable liquid junction potential and, ultimately, silver chloride into the system under study. In a modification suggested by Flengas and Rideal(3) and used in low-temperature molten nitrate systems, i.e.,

$$\text{Ag} \;\Big|\; \begin{matrix}\text{AgNO}_3\text{, dilute solution}\\ \text{in NaNO}_3\text{–KNO}_3\text{ eutectic}\end{matrix} \;\Big|\; \text{asbestos} \;\Big|\; \begin{matrix}\text{NaNO}_3\text{–KNO}_3\\ \text{eutectic,}\end{matrix}$$

the plug, consisting of an asbestos strand sealed through a glass tube, separates two virtually identical melts and is considered not likely to be the seat of a liquid junction potential. Diffusion of $AgNO_3$ into the system is slow but still possible.

The fact that glass itself is conducting at elevated temperatures has been appreciated for some time. Burt(10) and Stewart(11) both described sodium coulometers where sodium is transported quantitatively through soda glass and Delimarskii and his collaborators,(4,7) and Hauffe Vierk(8) have successfully employed half-cells of the t

Na, amalgamated with Hg, Sn and other
metals | Na glass | Na melt . . . . . .

to measure electrode potentials. The use of this partic type of half-cell is restricted to sodium-containing glas and melts. There is no evidence that it is gener applicable; certainly, Osteryoung(12) did not succeed with corresponding Li | Li glass | LiCl eutectic half-cell.

A compromise between the Delimarskii and Fleng Rideal types has been successfully used in this laborat for some time, i.e.

$$\text{Ag} \;\Big|\; \begin{matrix}\simeq 1\%\text{ solution of AgCl}\\ \text{in eutectic}\end{matrix} \;\Big|\; \begin{matrix}\text{glass}\\ \text{diaphragm}\end{matrix} \;\Big|\; \text{eutectic.}$$

Use is not made of the specific alkali content of the gla The diaphragm of very thin glass is simply sufficient prevent diffusion of silver ions into the melt under stu It makes effective electrical contact between the two hal of the cell, a robust diaphragm having a resistance of 200 5 000 Ω in the range 350–550° C.

The simplest type [Fig. 1(*a*)] is blown from any conveni glass tubing. Another type, related to the Luggin capilla lso shown [Fig. 1(*b*)]; it is used for current-potential dies with the diaphragm clamped against the working trode. Both have been widely used in LiCl–KCl eutectics emperatures up to 550° C. The thin glass does not withnd the solidification and ensuing expansion of the melt l each electrode was considered expendable since they are ily constructed. A fresh one is used for each new melt, ted to redness to remove any films of moisture, and filled m a stock solution of silver chloride in a purified sample his eutectic.

---

* Now at University of Pennsylvania, Philadelphia, U.S.A.

† Now at British Columbia Research Council, Vancouver, Canada.

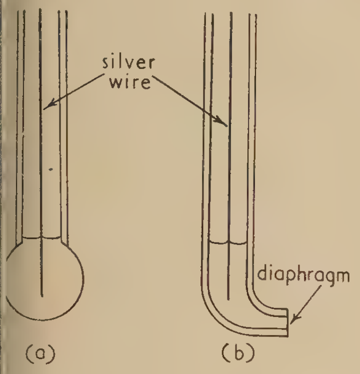


Fig. 1. Two types of reference half-cell

he performance of this type of half-cell has been investied in two ways: (1) by comparison over long periods of e of several half-cells immersed in the same eutectic and by investigating the response of the electromotive force the cell

$$\text{Ag} \left| \begin{matrix}\text{AgCl}\,(m_1),\\ \text{eutectic}\end{matrix} \right| \text{glass} \left| \begin{matrix}\text{AgCl}\,(m_2),\\ \text{eutectic}\end{matrix} \right| \text{Ag} \qquad (2)$$

changes in m_2, where m represents the molality of the er chloride. The reproducibility of these half-cells in LiCl–KCl eutectic is better than ±2·5 mV and is mainned indefinitely provided oxygen and water vapour are luded from the *inside* of the glass tubing (e.g. by means an inert gas) and solution of the silver wire prevented. e variation of the electromotive force of cell (2) with m_2, at constant m_1, (0·13 molal) is shown by the crosses Fig. 2, and can be compared with that predicted by the ation,

$$E = \frac{RT}{F} \ln \frac{m_2}{m_1} \qquad (3)$$

ere the ratio m_2/m_1 or the individual values of m_2 and m_1 small,(3) this relation is obeyed within experimental error. nificant negative errors observed at higher values of m_2 re not due to asymmetry potential or to uncontrolled ution of the silver wire in the melt to which the potential very sensitive. The results shown in Fig. 2 were obtained m two sets of experiments where the silver concentration) was varied (1) inside and (2) outside the glass electrode. At high values of m_2, the consequent difference in the ivities of the alkali metal ions of the eutectic inside and tside the diaphragm will give rise to a small but significant mbrane potential. It is assumed that the glass is permeable y to cations, i.e. that their combined transport number nity, and that the junction potential difference is therefore o given by the equation

$$E_{membrane} = \frac{RT}{F} \ln \frac{{m_2}^{Li+}}{{m_1}^{Li+}} = \frac{RT}{F} \ln \frac{{m_2}^{K+}}{{m_1}^{K+}} \qquad (4)$$

ctromotive forces corrected for this potential difference shown as circles on Fig. 2 and are seen to be in good agreement with equation (3). This conformity suggests that the activity coefficient of Ag^+ in this melt is constant over the concentration range 0–1 molal and is probably equal to unity.(13) The deviation of the *E versus* log m_2/m_1 plot from linearity which occurs when $m_2 \simeq 1{\cdot}3$ molal coincided with the point at which saturation of the melt with silver chloride was observed. No further increment in the silver ion concentration or silver electrode potential is possible after this and the electromotive force tended to a limiting value, in this case, of approximately 148 mV. This allows an approximate evaluation to be made of the solubility product of AgCl in this LiCl–KCl eutectic at 782° K, i.e.,

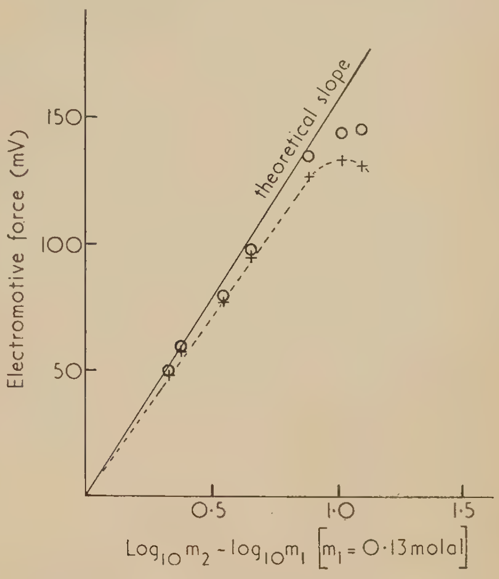


Fig. 2. The response of the electromotive force of cell (2) to changes in silver concentration compared with that predicted by equation (3)

$$\begin{aligned} K_{s782^\circ\text{K}} &= 1{\cdot}3 \times 19{\cdot}4 = 25{\cdot}2 \text{ g. ions}^2\ k_g \text{ eutectic}^{-2}.\\ &= 1{\cdot}7 \times 10^{-2}, \text{ in terms of g. ion fraction}\\ &\qquad \text{(g. ions per total g. ions present).} \end{aligned}$$

REFERENCES

(1) Brenner and Senderoff. *J. Electrochem. Soc.*, **101**, p. 31 (1954).
(2) Lorenz. *Die Elektrolyse Geschmolzener Salze*, Part III (Halle: Wilhelm Knapp, 1906).
(3) Flengas and Rideal. *Proc. Roy. Soc., A*, **233**, p. 443 (1956).
(4) Delimarskii. *Zapiskii Inst. Khim. Akad. Nauk U.S.S.R.*, **8**, (2), p. 23 (1946).
(5) Delimarskii, and Kharmovich. *Ukrain. Khim. Zhur.*, **15**, p. 340 (1949).
(6) Delimarskii and Kolotii. *Ukrain, Khim. Zhur.*, **16**, p. 438 (1950); **20**, p. 1169 (1954).
(7) Kolotii. *Ukrain. Khim. Zhur.*, **20**, p. 502 (1954).
(8) Hauffe and Vierk. *Z. Electrochem.*, **53**, p. 151 (1949).
(9) Coriou, Dirian and Huré. *J. Chim. Phys.*, **52**, p. 479 (1956).
(10) Burt. *Phys. Rev.*, **27**, p. 813 (1926).
(11) Stewart. *J. Amer. Chem. Soc.*, **53**, p. 3366 (1931).
(12) Osteryoung. *Diss. Abstr.*, **15**, p. 36 (1955).
(13) Kordes, Bergman and Vogel. *Z. Elektrochem.*, **55**, p. 600 (1951).

A heart pulse amplifier and ratemeter

By D. G. WYATT, M.A., D.Phil., The Nuffield Institute for Medical Research, University of Oxford

[*Paper first received* 9 *February, and in final form* 13 *July,* 1956]

A pulse amplifier and ratemeter for measuring heart rate are described. The self-biasing arrangement which is used in the amplifier greatly reduces the effects of changes in the mean level, shape, amplitude and duty cycle of the pulse. The ratemeter has rapid response and is suitable for continuous recording.

A record of heart rate can be obtained by using either a Thorp impulse counter,(1) or a ratemeter. These recording instruments may be operated, *via* an electrical or mechano-electrical circuit, by either blood pressure of electrocardiograph pulses.(2, 3) Capacitance manometers are widely used in physiological experiments, and therefore an electrical wave corresponding to the blood pressure pulse is, in many instances, already available. It is desirable that the operation of a heart rate recorder should continue uninterrupted in the presence of variations in pulse amplitude, duty cycle and pulse baseline. Further, since the pulses often have more than one maximum, it is necessary to include in the apparatus a means whereby multiple counting may be avoided.

THE PULSE AMPLIFIER

The basic circuit of the amplifier is shown in Fig. 1. A self-biasing arrangement is used, and the amplifier output is connected to a trigger valve, and thence to the Thorp counter and the ratemeter.

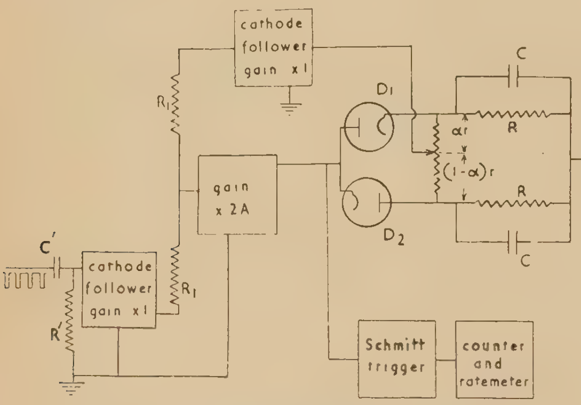


Fig. 1. Basic circuit of pulse amplifier

Voltage level of the pulse train. The double diode rectifier circuit shown in Fig. 1 is used to measure the amplitude of the amplified pulses. A certain fraction of the rectified voltage, depending on the setting of the potentiometer *r*, is fed to the input as grid bias. The trigger valve is adjusted so that the counting device operates when the amplifier output voltage passes through zero in the positive direction.

Let the voltage with respect to earth at the amplifier output be zero when no input pulses are applied. Consider a train of rectangular pulses coupled to the amplifier *via* a capacitor-resistor circuit *R'C'*, the latter having a time constant sufficiently large to ensure that there is no significant distortion of the pulses. If no grid bias from the rectifier were applied, the amplified pulses would be set about the line representing zero volts as shown in Fig. 2(*a*). When bias is applied, the voltage level of the pulses is altered as in Fig. 2(*b*). If the gain of the amplifier is sufficiently high, the effect o bias circuit is to make the fraction of the amplified p which lies above the line representing zero voltage, equ the fraction of the potentiometer resistance between the s and the cathode of D_1. This result is independent o pulse amplitude, but dependent on pulse duration frequency to an extent determined by the gain. The la twenty in the present design, and for a given setting of potentiometer, the baseline of the amplified pulses cha by 5% of the output amplitude for extreme change duration and frequency. This is illustrated in Fig. 3. pulses of Fig. 3(*b*) (with bias) are less rounded than thos Fig. 3(*a*) (without bias). This is because a portion of the s tooth waveform at the diode rectifiers is fed back to the in and the output is slightly distorted.

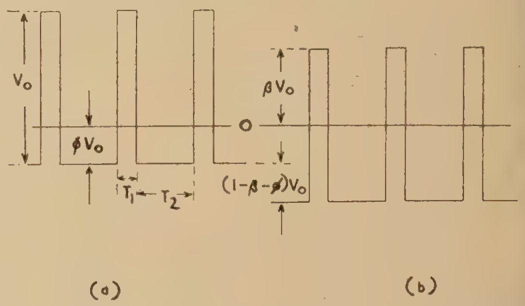


Fig. 2. Change of pulse baseline caused by self-bias

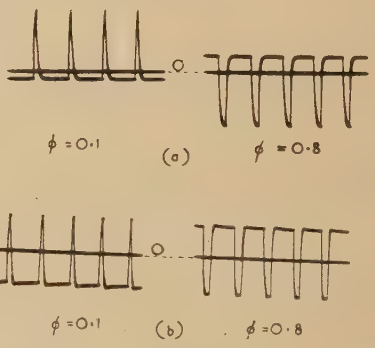


Fig. 3. Oscillograms of amplified pulse, potentiomete *r* set midway
(*a*) without bias; (*b*) with bias.

Thus, the level in the pulse wave at which counting occ can be set by means of the potentiometer *r*, and this sett is almost unaltered by large changes of pulse amplitude duty cycle.

The amplifier circuit. The circuit is shown in Fig. 4. five cathode followers serve as impedance transformers, set the standing voltages at their correct values. The me

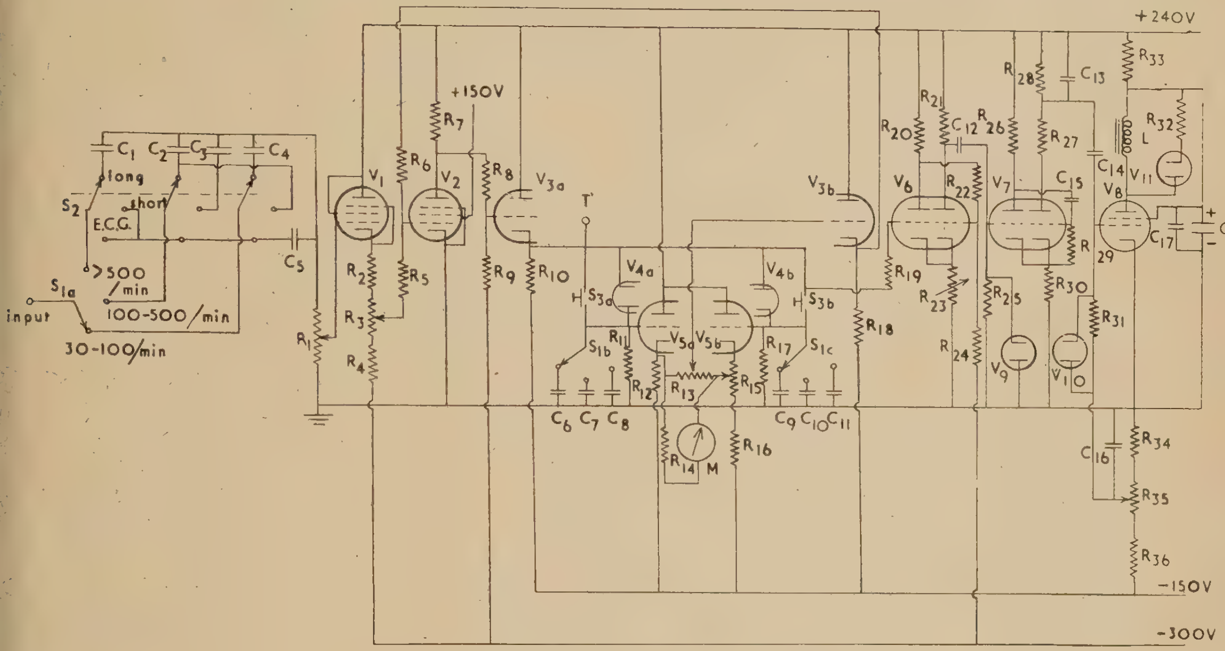


Fig. 4. Circuit diagram of pulse amplifier

R_1 = 5 MΩ
R_2, R_3 = 10 kΩ, ½ W
R_4 = 120 kΩ, 1 W
R_5 = 560 kΩ, ½ W, 5%
R_6 = 470 kΩ, ½ W, 5%
R_7 = 47 kΩ, ½ W, 5%
R_8 = 1·5 MΩ, ½ W, 5%
R_9 = 3·3 MΩ, ½ W, 5%
R_{10} = 75 kΩ, 1 W, 10%
R_{11} = 10 MΩ, ½ W, 5%
R_{12} = 75 kΩ, 1 W, 10%
R_{13} = 100 kΩ
R_{14} = 500 kΩ, ½ W, 1%
R_{15} = 2·5 kΩ
R_{16} = 75 kΩ, 1 W, 10%
R_{17} = 10 MΩ, ½ W, 5%
R_{18} = 75 kΩ, 1 W, 10%
R_{19} = 47 kΩ, ½ W, 5%
R_{20} = 120 kΩ, 1 W, 10%
R_{21} = 25 kΩ, 2 W, 10%
R_{22} = 470 kΩ, ½ W, 5%
R_{23} = 500 Ω w.w.
R_{24} = 2 MΩ, ½ W, 5%
R_{25}, R_{26} = 220 kΩ, ½ W, 10%
R_{27} = 120 kΩ, 1 W, 10%
R_{28} = 25 kΩ, ½ W, 10%
R_{29} = 1·5 MΩ, ½ W, 5%
R_{30} = 17 kΩ, ½ W, 5%
R_{31} = 1 MΩ, ½ W, 10%
R_{32} = 2 kΩ, ½ W, 10%
R_{33} = 5 kΩ, ½ W, 10%
R_{34}, R_{35} = 50 kΩ, ½ W, 10%
R_{36} = 220 kΩ, ½ W, 10%
C_1 = 0·1 μF
C_2 = 0·5 μF
C_3 = 0·05 μF
C_4 = 1·5 μF
C_5 = 0·01 μF
C_6 = 3 μF, 5%
C_7 = 1 μF, 5%
C_8 = 0·25 μF, 5%
C_9 = 3 μF, 5%
C_{10} = 1 μF, 5%
C_{11} = 0·25 μF, 5%
C_{12} = 100 pF
C_{13} = 0·05 μF
C_{14} = 0·25 μF
C_{15} = 0·005 μF
C_{16} = 1 μF
C_{17} = 0·1 μF
C_{18} = 100 μF

V_1, V_2 = EF86
V_3 = ECC82
V_4 = EB34
V_5 = ECC82
V_6, V_7 = 6SN7GT
V_8 = 6V6
V_9, V_{10}, V_{11} = EA50

L = Thorpe counter and ratemeter relay coils

M = meter, 0–100 μA

ading is a measure of the pulse amplitude applied to the :hmitt trigger, and this may be varied by means of the gain ntrol R_1. The pulse level control R_{13} is best set midway, though a value different from this may be necessary in der to avoid multiple counting. The pulse rate selector vitch S_1 has three ranges, 30–100 pulses/min, 100–500 ılses/min, and in excess of 500 pulses/min. The switch S_2 ıables the time constant of the input circuit to be altered. respiratory phase, if present, can be effectively blocked hen this switch is at "short." If a sudden change in mean put voltage should occur, it has less effect on the equilibrium f the amplifier if S_2 is at "long." The push-button S_3 is rovided so that the diode capacitors can be instantly disıarged should a very large spontaneous voltage change ccur at the input. In this way, lengthy paralysis of the mplifier is avoided.

The backlash of the Schmitt trigger is 0·5 V; therefore the mplitude of the pulses must exceed this in order to be ounted. The meter gives maximum reading when the pulse mplitude is 50 V, which corresponds to an input voltage of ·5 V.

The valves which follow the Schmitt trigger are not fundaıental to the amplifier. Their function is to generate a urrent pulse of width 10 ms and amplitude 40 mA, suitable or the operation of the Thorp counter. The short duration f this pulse ensures that the counter has time to reset before ıe occurrence of the succeeding pulse.

Initial adjustments of the amplifier. The gain control R_1 is set to minimum, and the rate selector S_1 to maximum rate. The slider of the pulse level control R_{13} is moved to the cathode of V_{5a}, and a high impedance voltmeter (10 V, full-scale deflexion) is connected between earth and the junction of the diodes (the test socket T). The cathode resistor R_{23} of the Schmitt trigger is adjusted so that the counter operates when the voltmeter reaches zero from a negative voltage exceeding the backlash (approximately 0·5 V). This change of voltage is made by altering the bias control R_3. When R_{23} is correctly set, R_3 is adjusted so that the voltmeter reads zero. The slider of R_{13} is now moved to join the slider of R_{15}, which is altered until the voltmeter again reads zero. The meter M now remains at zero for all settings of the level control R_{13}. Finally, the bias potentiometer R_{35} is set so that the mean current through the counter coil is 5 mA when pulses at a frequency of 10 pulses/s are applied to the amplifier.

A stabilized power supply of the type described by Attree is used.(4)

THE RATEMETER

The ordinary integrating circuit, when used for measuring heart rate, has the alternative disadvantages of long response time or fluctuating output. An arrangement which records the frequency of equally spaced pulses with neither of these disadvantages has been demonstrated by Field.(5) The main features of Field's device are the use of relays and an electrometer sampling circuit. In the ratemeter described here, these features have been combined with the charge transfer principle as used in the diode pump circuit.(6)

The basic circuit is shown in Fig. 5. When operating, the capacitor C_1 is initially connected to a source of e.m.f. V_0, whence it receives a charge Q_0. When a pulse occurs, the relay S_1 closes for a time small compared with RC_2, thus allowing charge on C_1 to be transferred to C_2; a short time after S_1 has closed, the relay S_3 closes momentarily, enabling the potential of C_2 to be recorded by the electrometer valve voltmeter. When a large number of pulses have occurred, and the rate is steady, the system reaches equilibrium. The capacitor C_3 loses no significant charge in the intervals between pulses, therefore the reading of the valve voltmeter remains steady. For this reason, as Field states, the integrating time constant, and therefore the response time, can be made smaller than in ratemeters which record a mean value of integrated voltage.

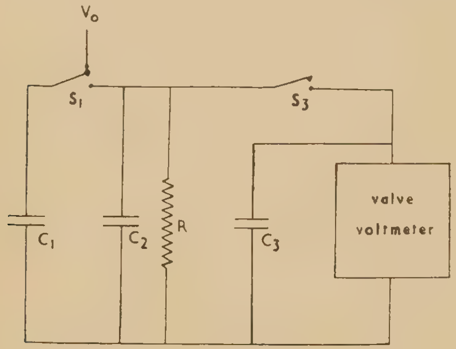


Fig. 5. Basic circuit of ratemeter

Sensitivity and linearity. Consideration of the basic circuit shows that: (i) the maximum potential across C_2 at equilibrium, and at a given rate f/second, is proportional to V_0, and is approximately proportional to C_1/C_2; (ii) as the interval between pulses approaches a value large compared with RC_2, the potential across C_2 immediately after the occurrence of a pulse approaches a constant value; and (iii) the slope of the response curve (valve voltmeter reading *versus* pulse rate) will diminish at large rates more noticeably when the value of C_1/C_2 is large than when it is small. The form of the response curve, and its dependence on C_1/C_2, is shown in Fig. 6.

In the region where fRC_2 is about 1, the relationship between ψ (the proportion of the charging voltage V_0 which appears across C_3 at equilibrium) and f is more linear than at first might be supposed. The slope of the response curve increases with f, because ψ is measured immediately after the charge sharing has taken place. However, this is partly offset by the decrease in slope brought about by the charge-sharing process itself. The desirable features which the ratemeter should possess are linearity over a wide working range, and large output over this range. However, the choice of a suitable value of C_1/C_2 is also governed by consideration of response time, which is approximately proportional to RC_2. The value of C_1/C_2 chosen for the present instrument was 0·02, and the range of operation was limited to $0{\cdot}5 < fRC_2 < 5$. Over this range, the deviation of the response curve from the straight line joining those points on the curve for which $fRC_2 = 0{\cdot}5$ and 5 respectively does not exceed ±1% full scale.

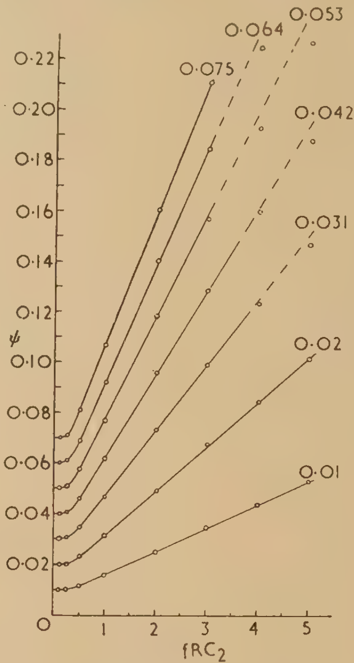


Fig. 6. Response curves of ratemeter for differen values of C_1/C_2

The dotted lines show the departure from linearity of the calculated points. ψ is the ratio of the output voltage tc the charging voltage V_0.

Response time. Suppose that the ratemeter is in equ brium at a certain rate, and that the rate is then chang instantaneously, to a new value. If the increments of cha added to C_2 (Fig. 5) at each pulse were constant, and if were not connected, the peaks of the voltage pulses acr C_2 would lie on an exponential curve having a time consta RC_2. The time taken for 99% of any voltage change occur would be independent of the final rate, and equal 4·6 RC_2 s. However, the charge sharing mechanism wh is used causes the charge increment received by C_2 at ea pulse to decrease as the voltage across C_2 increases. T reduces the response time, especially at the higher rat Also, the presence of the capacitor C_3 requires a larger fl of charge than would otherwise occur, and this increases response time, particularly at the lower rates. Therefo both the effects make the response time less for high ra than for low ones. A consequence of this is that the ti taken for a given change of voltage across C_2 is more wh the change is a decrease (final rate low) than when it is increase (final rate high). When RC_2 is 0·6 s, the upper r 500 pulses/min, and the lower rate 50 pulses/min, the calcula time for 99% of the change between these limits to complete is 2·7 s when the rate increases, and 3·2 s wh it decreases. (A formula which may be used for calculati either the 99% response time, or the percentage respon when a given number of pulses have occurred, is given the Appendix.)

The ratemeter circuit. The complete circuit is shown Fig. 7. It consists of the basic ratemeter circuit of Fig followed by the electrometer valve voltmeter. The output the latter operates a meter and a single valve balanc amplifier.

The instrument has three ranges, measuring rates 10–0 pulses/min, 20–200 pulses/min and 50–500 pulses/min. he corresponding values of the time for 99% response are pproximately 15 s, 7·5 s and 3 s.

Three single-pole balanced relays were at hand, and these ere modified by fitting the armatures of S_1 and S_3 with ort segments of polystyrene, and by mounting the stationary ntacts on blocks of the same material. The operating coils S_1 and S_2 are connected in series with the power valve the heart-rate amplifier. The relay S_1 remains closed for a period of 15 ms and S_3 closes 2 ms after S_1 has closed, for a period of 2 ms. Certainty of contact, and absence of contact bounce, is essential for successful operation.

The Thorp counter and the ratemeter may be used simultaneously if desired, provided that the ratemeter is connected on the side of the Thorp counter away from the anode of the power valve; otherwise the voltage pulses at the latter may interfere with the operation of the electrometer valve in the ratemeter.

The value of C_3 was chosen to be 0·01 μF, in order that

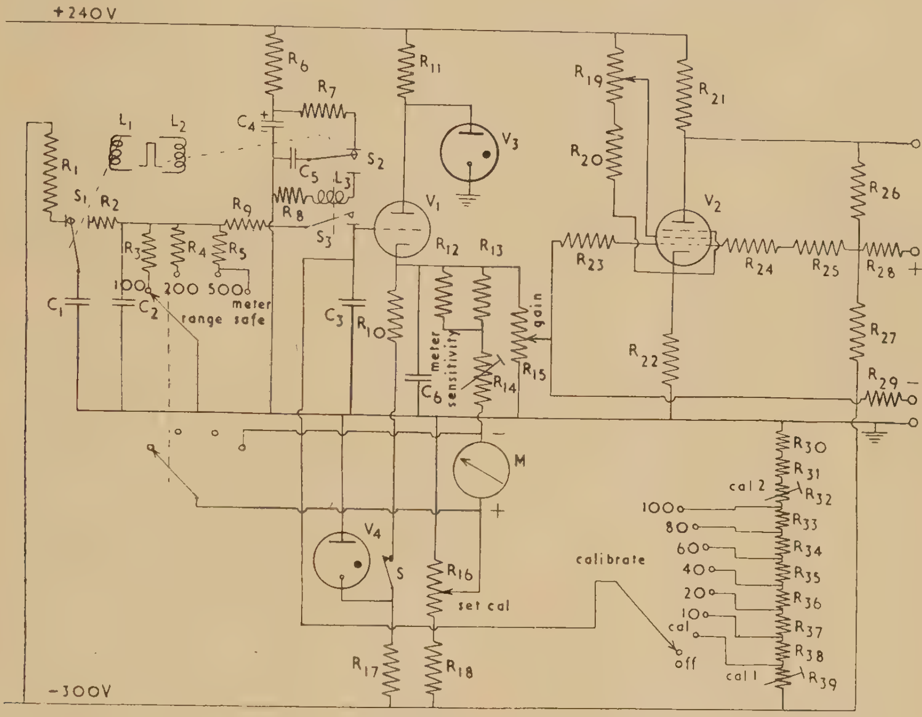

+240 V
−300V
R1
R2
S1
L1
L2
C4
C5
L3
S2
S3
R6
R7
R8
R9
R3
R4
R5
100
200
500
meter
range
safe
C1
C2
C3
R10
V1
V3
R11
R12
R13
meter sensitivity
C6
R14
gain
R15
R19
R20
R21
V2
R23
R24
R25
R26
R28 +
R27
R29 −
R22
M
V4
S
R16
set cal
R17
R18
calibrate
100
80
60
40
20
10
cal
off
cal 2
cal 1
R30
R31
R32
R33
R34
R35
R36
R37
R38
R39

Fig. 7. Circuit diagram of ratemeter

R_1 = 3 MΩ, ½ W, 10%
R_2 = 10 kΩ, ½ W, 20%
R_3 = 15 MΩ, ½ W, 1%
R_4 = 7·5 MΩ, ½ W, 1%
R_5 = 3 MΩ, ½ W, 1%
R_6 = 4·7 kΩ, ½ W, 10%
R_7 = 100 kΩ, ½ W, 10%
R_8 = 10 kΩ, ½ W, 5%
R_9 = 10 kΩ, ½ W, 20%
R_{10} = 170 kΩ, ½ W, 5%
R_{11} = 75 kΩ, ½ W, 20%
R_{12} = 5 MΩ, ½ W, 10%
R_{13} = 250 kΩ, ½ W, 1%

R_{14} = 50 kΩ, w.w.
R_{15} = 250 kΩ
R_{16} = 10 kΩ, w.w.
R_{17} = 100 kΩ, 1 W, 20%
R_{18} = 1 MΩ, ½ W, 10%
R_{19} = 20 kΩ, w.w.
R_{20} = 25 kΩ, 1 W, 10%
R_{21} = 100 kΩ, ½ W, 5%
R_{22} = 750 Ω, ½ W, 5%
R_{23}, R_{24} = 5 MΩ, ½ W, 1%
R_{25} = 500 kΩ, ½ W, 10%
R_{26} = 1 MΩ, ½ W, 1%
R_{27} = 2 MΩ, ½ W, 1%

R_{28}, R_{29} = 220 kΩ, ½ W, 10%
R_{30} = 2 MΩ, ½ W, 1%
R_{31} = 250 kΩ, ½ W, 1%
R_{32} = 500 kΩ
R_{33}, R_{34}, R_{35}, R_{36} = 50 kΩ, ½ W, 1%
R_{37}, R_{38} = 25 kΩ, ½ W, 1%
R_{39} = 50 kΩ, w.w.

C_1 = 0·0040 μF, 5%
C_2 = 0·20 μF, 5%
C_3 = 0·01 μF, 10%
C_4 = 16 μF, 350 V
C_5 = 0·1 μF, 350 V, 5%

V_1 = ME1400
V_2 = EF86
V_3, V_4 = 85A2

L_1, L_2, L_3 = relay coils

M = meter, 0–100 μA

S = thermal delay switch
(All 1% resistances are of the highly stable type.)

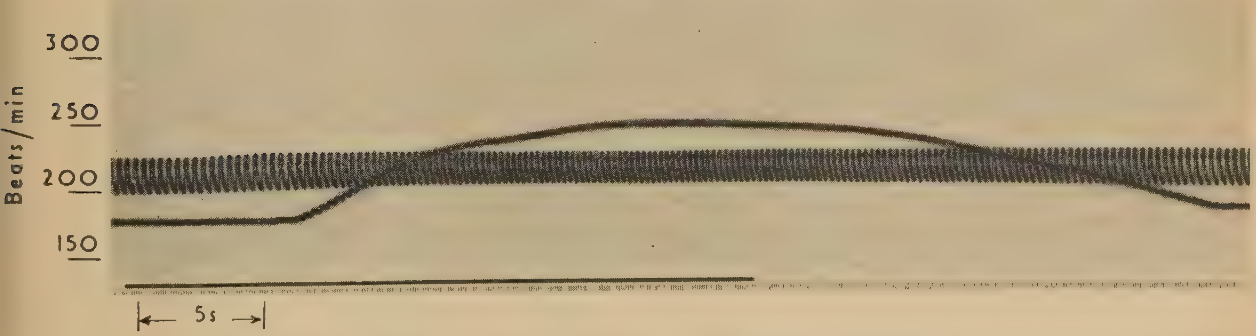


Fig. 8. Mature foetal lamb, arterial pressure and heart rate

Electrical stimulation of the left stellate ganglion was applied for the duration of the marker (lower solid line).

the grid current of the electrometer valve (10^{-11} A) should not cause significant change of grid voltage in the intervals between those pulses which occur at the lowest rate (10 pulses/min).

A pulse generator, the frequency of which was measured directly, was used to adjust the sensitivity of the ratemeter in accordance with the meter scale. This was achieved by alternate adjustment of the "meter sensitivity" and "set cal" controls, when the applied rate was full scale and 10% of full scale respectively.

A calibrating circuit is included in the instrument. The voltage level of this circuit, as well as the potential difference across it, can be altered by means of the controls "cal 1" and "cal 2." In this way the several positions of the calibrate switch were made to correspond to definite points on the meter scale. The capacitors C_1, C_2 and C_3 have polystyrene insulation so that no appreciable error is introduced by leakage or by dielectric absorption.

When finally tested the ratemeter was linear within ±1% between full scale and 20% of full-scale deflexion. At 10% of full-scale deflexion, the error was $+2\frac{1}{2}$% on the two lower ranges and +5% on the highest range.

The single valve balanced amplifier is intended for use with a pen recorder and cathode-ray oscilloscope. It is possible to record a selected portion only of the range in use, by means of a suitable backing-off voltage and further amplification. In this way, high sensitivity can be obtained. An example of continuous recording is shown in Fig. 8. Throughout this record the rate given by the ratemeter agrees with that measured from the pulse interval, within the limits of accuracy of measurement of the latter (±5%).

ACKNOWLEDGEMENTS

The mechanical design and construction of the apparatus was carried out by Mr. M. Ritchings, and Mr. P. J. Tosh reconstructed the relays. I wish to thank Dr. G. S. Dawes for discussion and for the record shown in Fig. 8.

APPENDIX

Pulse amplifier

If the value of r (Fig. 1) is sufficiently large not to affect the operation of the rectifier circuits, the effect of the grid bias produced by the diode rectifiers is to move the pulse baseline an amount $(1 - \beta - \phi)V_0$, as shown in Fig. 2, where

$$\beta = (1 - \phi + \alpha A)(1 + A)^{-1} \quad \text{and} \quad \phi = T_1/(T_1 + T_2) \; (1)$$

Therefore, if α is set at a given value, and ϕ varies over its maximum range, namely, from 0 to 1, the change which occurs in the fraction β is $(1 + A)^{-1}$. This quantity can be made small by making A large, and β is then approximately equal to α.

Ratemeter

It can be shown (Fig. 5), either by considering the eq brium condition or by determining the voltage on C_2 at nth pulse and setting n equal to infinity, that the proport of the charging voltage V_0 which appears across C_3 equilibrium is

$$\psi = \left\{1 + C_2/C_1[1 - \exp -(1/fRC_2)]\right\}^{-1}$$

It is this result which has been used in calculating Fig Also,

$$\psi = C_1/(C_1 + C_2) \qquad fRC_2 \ll 1$$

$$\psi = fRC_1/(1 + fRC_1) \qquad fRC_2 \gg 1$$

In order to define the response time of the rateme suppose that equilibrium has been reached at rate f_1, that the rate now changes instantaneously to f_2. Let value of ψ after n pulses have occurred at rate f_2 be ψ_n, when equilibrium is reached at rate f_2 be ψ_2, and that at r f_1 be ψ_1. Then the proportion of the final change in ψ w is completed after n pulses is

$$\sigma = \frac{\psi_n - \psi_1}{\psi_2 - \psi_1} \doteq 1 - \left[\frac{C_3}{C_1 + C_2 + C_3} + \frac{C_2}{C_1 + C_2 + C_3}\exp(-1/f_2RC_2)\right]^n$$

This formula may be written in terms of the time t requi for a given value of σ to be reached:

$$t = n/f_2 = (RC_2/f_2RC_2).[\log(1 - \sigma)] \Big/ \left\{\log\left[\frac{C_3 + C_2\exp(-1/f_2RC_2)}{C_1 + C_2 + C_3}\right]\right\}$$

This result is realizable in practice only when the value is integral.

When (C_3/C_2) and $(C_1/C_2) \rightarrow 0$, which means that charge increment per pulse received by C_2 tends to a cons value at all rates, the formula for σ reduces to the sim exponential form

$$\sigma = 1 - \exp(-t/RC_2)$$

REFERENCES

(1) Thorp, R. H. *Brit. J. Pharm.*, **3**, p. 271 (1948).

(2) de Burgh Daly, M., and Schweitzer, A. *J. Physi* **111**, p. 50*P* (1950).

(3) Dawes, G. S. *J. Physiol.*, **112**, p. 29*P* (1951).

(4) Attree, V. H. *J. Sci. Instrum.*, **25**, p. 263 (1948).

(5) Field, D. V. *J. Physiol.*, **129**, p. 4*P* (1955).

(6) Cooke-Yarborough, E. H., and Pulsford, E. *Proc. Instn Elect. Engrs*, **98** (II), pp. 191, 196 (1951).

Laboratory and workshop notes

A window material for high temperature X-ray cameras

By A. G. Provan, B.Sc., A.R.T.C., A.R.I.C., B. A. Shaw, and G. I. Williams, Ph.D., Fulmer Research Institute Ltd., Stoke Poges, Bucks

[*Note received* 12 *April*, 1956]

uring the course of an investigation, some difficulty was xperienced in obtaining a suitable window material for peration in a high temperature X-ray camera under vacuum onditions.

Pure aluminium foil of thickness 0·001–0·003 in. had reviously been used for this purpose, but under the prevailing onditions, with a window size of 4 × 0·4 in., the external ressure caused a marked concavity with consequent creasing nd in many cases failure by rupture.

The difficulty was finally overcome by using a foil hardened y the addition of 5% silicon and by cold rolling, this material aving sufficient strength and rigidity even at thicknesses of ·0015–0·002 in. to conform to the contours of the camera nder reduced pressure. This silicon content has a negligible ffect on the X-ray absorption of the aluminium foil.

The method of foil preparation is by hot rolling in a boratory mill a slab of dimensions 3·5 × 1·5 × 0·375 in. lloyed and cast by conventional methods. From the hot olled material after annealing, blanks of 3 × 1 in. are cut and old rolled, if necessary, between annealed Dural sheet to a hickness of 0·002 in. For small windows, a further reduction thickness to 0·001 in. may be effected by reducing to ·004 in. before the final anneal, but in this case a pack of olished stainless steel may be necessary to give a sufficiently mooth surface, and to ensure freedom from pinholes.

The window may then be affixed to the camera slit by means f a small quantity of thermosetting plastic glue (Araldite o. 1). Vacua as low as 10^{-5} mm of mercury have been btained at window temperatures up to 200° C without ilure.

n internally metallizing a betatron toroid by vacuum deposition

By K. R. Allen, B.Sc., A.Inst.P., F. Ashworth, B.Sc., Ph.D., A.Inst.P., and G. Siddall,* Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17

[*Note first received* 7 *February, and in final form* 8 *August*, 1956]

here are many instances where a conducting metallic oating has to be produced on the internal surface of apparatus. method is described which forms such a coating by vacuum eposition. Technical details relating to a particular example re discussed. In this application the resistivity must have value between 20 and 80 Ω per square and this method ermits sufficiently close control. The internal surface of a etatron toroid was coated with metal film of resistivity 56 Ω er square.

The simplest filament arrangement necessary to produce a early uniform film on the inner surface of the toroid is two arallel wires concentric within the toroid, as shown in ig. 1. The filaments were chromium-plated, the required hickness being determined by small scale evaporation tests.

In order to produce a hard and stable film, the toroid was evacuated to a pressure lower than 10^{-4} mm of mercury, and to outgas the glass surface its temperature was raised to 350° C. Chromium was then evaporated from the filament by passing a heavy current through it.

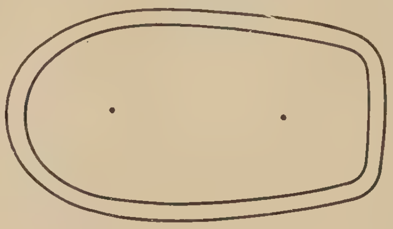


Fig. 1. Section through toroid showing position of filaments

The general layout of the apparatus is shown in Fig. 2. An oven, 2 ft 6 in. cube, was fitted with a pumping system. The oven had double walls lagged with asbestos wool and was lined with aluminium foil. The total rating of the oven was 12 kW with full range control by two variable autotransformers. Chromel-alumel thermocouples were placed at various points within the volume so that the temperature distribution could be checked during the heating cycle.

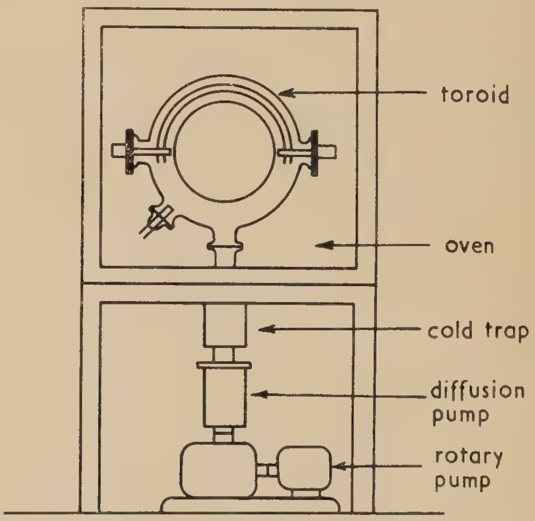


Fig. 2. General layout

The pumping system consisted of a Metrovac type O3B oil diffusion pump with a solid carbon dioxide trap backed by a Metrovac type D.R.1 rotary pump. The pumping line projected through the base of the oven and was sealed by means of a silicone gasket between flanges clamped with split rings.

The cleaning procedure adopted was as follows:

(i) the toroid was filled with a 50% solution of nitric acid and allowed to soak for thirty minutes;

(ii) it was washed in running tap water for thirty minutes;

(iii) it was rinsed with distilled water and then with pure alcohol and allowed to dry in a dust free atmosphere.

Molybdenum filaments plated with chromium metal were threaded into the toroid using a thin leader wire and finally clamped in the correct positions using the electrodes as shown in Fig. 3. Manipulation was difficult but the clamping electrodes were designed to simplify this (only one half of the toroid could be coated at one time since the filaments could not be made to encircle completely the whole toroid. Two runs were therefore necessary).

---

* Now at Edwards (High Vacuum) Ltd., Crawley, Sussex.

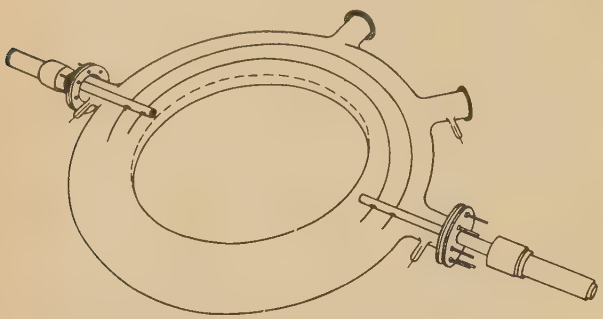


Fig. 3. Toroid with filaments assembled

The electrodes were sealed by means of silicone rubber gaskets (G in Fig. 4), clamped between the glass flange and the steel flange plate (*F*). The steel clamping shaft (*C*) was sealed by screwing down the steel cap hard against the copper bearing surface (*K*).

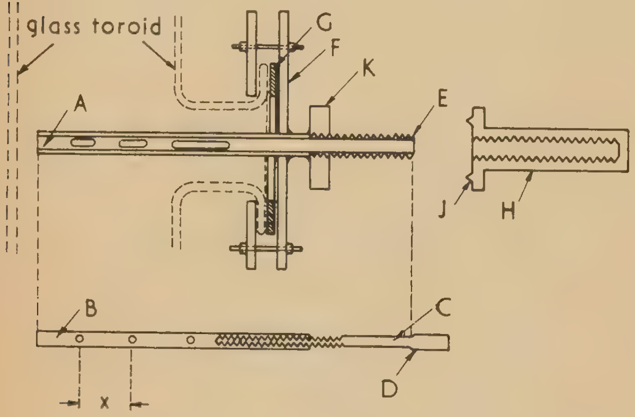


Fig. 4. Electrode assembly details

A, outer copper tube; *B*, inner copper rod; *C*, steel clamping shaft; *D*, knurled head; *E*, tube threaded for sealing cap; *F*, annular steel clamping ring brazed to tube; *G*, silicone rubber gasket; *H*, steel cap; *J*, knife edge; *K*, soft copper block brazed to tube; *x*, filament spacing distance.

The third port was fitted with a glass flange having two $\frac{1}{8}$ in. diameter tungsten leads. A small evaporator was attached to these. It consisted of six inches of 0·015 in. diameter molybdenum wire wound into a conical basket enclosing about 200 mg of pure chromium metal. The toroid assembly was mounted in a frame and transferred to the oven. The fourth port was sealed to the pumping line using a silicone rubber gasket.

Power supplies were connected to the filaments and the thermocouples were arranged at various points in the oven. The heaters were screened with asbestos paper to prevent thermal stresses in the glass due to non-uniform direct radiation.

The toroid was evacuated to less than 10^{-4} mm of mercury. The following heating cycle was used:

(i) a rise of 2·5° C per minute up to 200° C;
(ii) a rise of 5° C per minute from 200 to 350° C.

During the heating cycle the pressure was measu continuously.

When the temperature reached 350° C with the press less than 10^{-4} mm of mercury a current of 160 A was pas through the two wires in parallel. Chromium was evapora from the filaments and condensed on the inner surface of toroid. The third port was coated by passing a curren about 15 A through the evaporator.

After the evaporation the oven was allowed to cool slo to room temperature and the electrode system dismant The film was found to be hard and uniform and had a m resistance of 56 Ω per square.

The process was repeated after reassembling the electr system to coat the second half of the toroid.

The difficulties which were experienced in the developm of this method were mainly concerned with the vacu technique at the elevated temperature. Once the sea problems had been solved and some experience gained the manipulation of the filaments the procedure was strai forward. This method has wide application in the producti of uniformly conducting films on the internal surfaces glass envelopes of electronic equipment.

We wish to thank Dr. Willis Jackson, Director of Resea and Education, and Mr. B. G. Churcher, Manager of Research Department of Metropolitan-Vickers Electrical Ltd., for permission to publish this note.

A simple rotary film evaporator

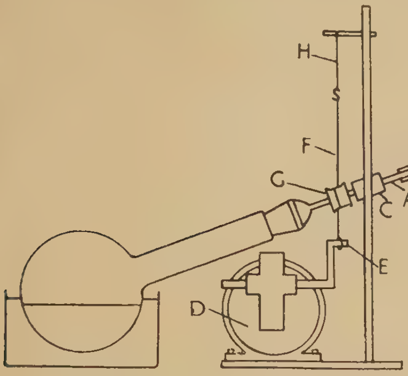
By B. B. Marsh, M.Sc., Ph.D., and P. M. Notting ham, M.Sc., Ph.D., Dominion Laboratory, Departmen of Scientific and Industrial Research, Wellingto New Zealand

[*Note received* 4 *April*, 1956]

The wide application of rotary film evaporators to problem of concentrating unstable materials in solution illustrated by the number of designs published recently, a by the commercial production of several types. The o difficulty in construction, that of connecting a rotating fla to a stationary vacuum line, has been overcome in a numb of ways: a ball joint,(1,2) a packed vacuum gland of spec construction,(3) and an all-glass hypodermic syringe(4) ha each been used. An evaporator is described below in wh this difficulty has been eliminated rather than surmount with resulting advantages in simplicity, cost of constructi and ease of operation. The apparatus differs from tho mentioned above in that the flask reverses its direction movement after rotating through 360°, the resulting limit torque being completely accommodated by the attach vacuum line.

The evaporator is illustrated in the figure. A flask suitable size (50–1000 ml.) is attached by a standard ta joint to a glass tube *A* of internal diameter 5–6 mm, upper end of which is connected to the vacuum system pressure tubing *B*. The metal collar *C*, fixed to the supporti stand, serves as a bearing for tube *A* and holds it at about to the horizontal. The geared motor *D* (55 rev/min) drives crank-shaft *E*, to which a length of cord or light flexi chain *F* is attached by a loose-fitting collar. After passi round a flanged metal wheel *G* cemented to tube *A*, the co *F* is joined to a spring or elastic band *H* which is fixed to t supporting stand. The circumference of the wheel G slightly less than the diameter of the path traced by the cra shaft *E* to ensure a flask rotation of at least 360°.

With a pressure of about 1 mm of mercury and a soluti mperature of 20° C (bath 21·5° C), the rate of evaporation f water in this apparatus exceeds 50 ml./h, while at 45° C 1° C) over 300 ml./h are removed. Slightly lower rates of aporation are obtained with a water pump; with a pressure



Rotary film evaporator

f 18 mm of mercury the rate is about 70 ml./h at 30° C 1·5° C) and 230 ml./h at 45° C (50° C).

This note is published by permission of the Director of his Laboratory.

REFERENCES

1) Craig, L. C., Gregory, J. D., and Hausmann, W. *Analyt. Chem.*, **22**, p. 1462 (1950).
2) Volk, M. E. *Analyt. Chem.*, **27**, p. 1207 (1955).
3) Partridge, S. M. *J. Sci. Instrum.*, **28**, p. 28 (1951).
4) Numerof, P., and Reinhardt, K. *Analyt. Chem.*, **25**, p. 364 (1953).

An improved design of radio-frequency ion source

By H. R. Allan, M.A., Ph.D., and N. Sarma, Imperial College of Science and Technology, London, S.W.7

[*Note received* 25 *April*, 1956]

ince its introduction by Thonemann and others* the radio-requency ion source has been widely adopted for use in article accelerators. Its chief advantages over earlier types re the high yield of monatomic ions and their low spread energy. In such an ion source, a radio-frequency electrode-ess discharge is produced in the gas, contained in a glass or uartz vessel at a pressure of about 20 μ, and the ions are xtracted through an aluminium canal under the influence of d.c. potential (3 to 5 kV) applied to a tungsten probe. The nly critical design feature lies in the geometrical disposition f the conducting and the insulating materials close to the anal. The usual arrangement is to have a glass or quartz ollar that fits over the canal and projects a little into the lasma. In operation, the tip of this collar becomes positively harged (to approximately the probe voltage) and so focuses ne ions being drawn from the plasma into the aluminium anal. If quite critical geometrical conditions are satisfied, a arge fraction (as much as 10%) of the ion current is extracted. he remainder of the ion current, of course, hits the luminium, and in time causes pitting, with sputtering of luminium on to the quartz collar and on to the walls of the ischarge tube.

In early work done by the authors in conjunction with Dr. . Manning, a modification of the ion source described by Moak and others† was used (Fig. 1). The present difference in design consists of the provision of a glass inner envelope. At the appropriate pressure, the radio-frequency discharge is confined within this inner envelope. In the course of time, the inner surface becomes coated with a deposit which has the effect of seriously reducing the percentage of monatomic ions. Use of an inner envelope is an advantage, since changing it is a relatively simple matter, whereas the outer envelope must be specially selected to withstand high pressures (over 10 atm) without ill-effects.

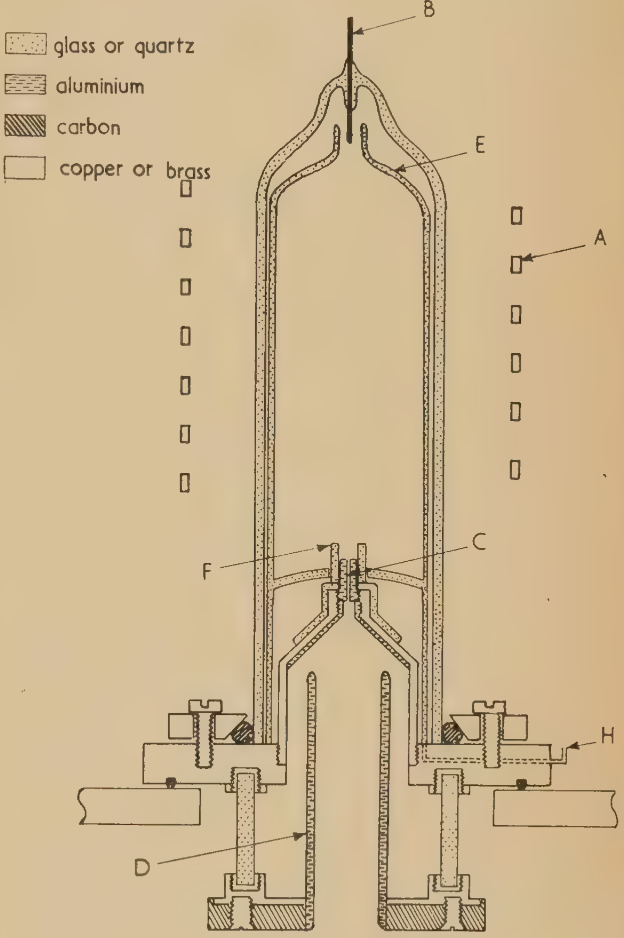


Fig. 1. Ion source: first design

A, radio-frequency coil; *B*, probe; *C*, aluminium canal; *D*, Van de Graaff focusing electrode; *E*, inner envelope; *F*, quartz collar; *G*, quartz bottle; *H*, gas inlet.

In place of the inner envelope a quartz bottle (Fig. 2) has been introduced. This sits on an adjustable platform and can be moved up or down by a screw thread so that the height above the canal may be accurately controlled. This bottle has a flat base with a central hole (diameter 3 mm) which must be coaxial with the canal (diameter 1·5 mm). It is not difficult to arrange this since the bottle can be supplied with the hole accurately at the centre of the circular base, and precision in construction of the mounting platform is easily achieved.

In operation it is found that at the appropriate gas pressures a plasma is formed only within the bottle and the hole in the base acts just like the quartz collar of Fig. 1 in focusing the ions into the canal. However it is now a simple matter to adjust the height of the bottle to the optimum for giving maximum extracted beam. The setting was found to be quite critical, 0·1 mm producing a significant change. It was essential to use a bottle made entirely of quartz since any arrangement involving glass resulted in electrical breakdown.

---

* Thonemann, P. C., Moffatt, J., Roaf, D., and Sanders, J. H. *roc. Phys. Soc.* [*London*], **61**, p. 483 (1948).

† Moak, C. D., Reese, H., and Good, W. M. *Nucleonics*, **9**, p. 18 (1951).

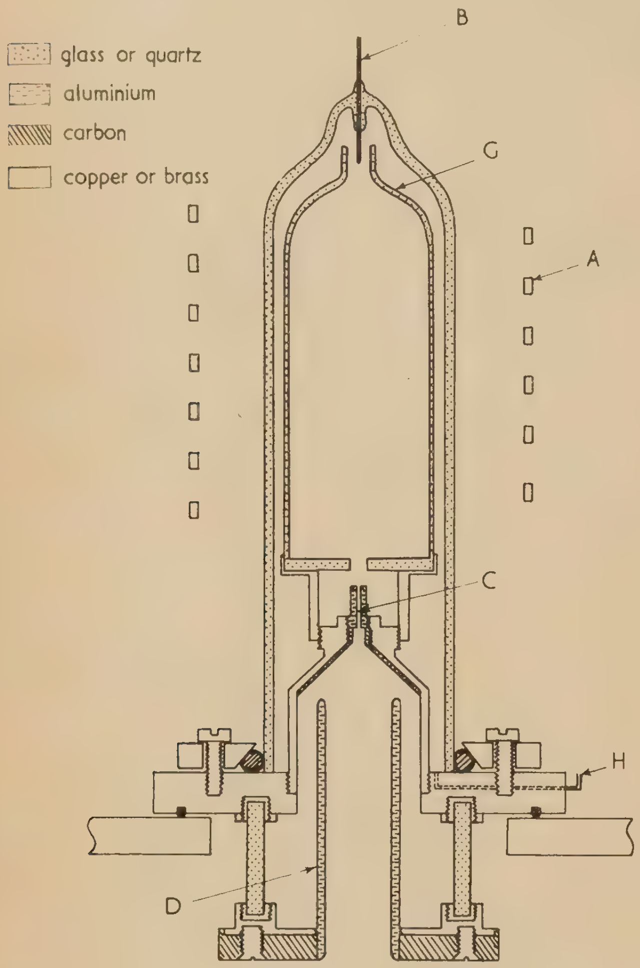


Fig. 2. Ion source: improved design
A, radio-frequency coil; *B*, probe; *C*, aluminium canal; *D*, Van de Graaff focusing electrode; *E*, inner envelope; *F*, quartz collar; *G*, quartz bottle; *H*, gas inlet.

For testing purposes the beam from the ion source was accelerated to 20 kV by a metal-rectifier Cockcroft–Walton circuit and magnetically analysed. The proton beam was collected in a Faraday cage biased to eliminate secondary-electron emission. With a power input to the radio-frequency oscillator of 120 W and a probe current of 5 mA the proton beam exceeded 300 μA whereas the previous ion source under comparable conditions gave only 100 μA.

A secondary microwave attenuator

By H. A. Prime, M.Sc., A.M.I.E.E., Brush Electrical Engineering Co. Ltd., Loughborough

[*Note received* 4 *April*, 1956]

The majority of secondary or coarse attenuators employed in the microwave range make use of some form of tapered, resistive vane, which can be moved parallel to and from narrow face of the guide into the strong field region at centre, in order to achieve the required amount of attenua The principal design requirements to be met are: (i) that longitudinal axis of the vane should be maintained par to the wave-guide axis for both directions of movemen the lead screw or screws; (ii) that the length of the lead sc projecting within the wave-guide should not pro reflexions, otherwise the match between the vane and guide will not be sustained as the attenuation is increa and (iii) that the vane material and its dimensions should chosen to give a good match to the guide impedance. first two of these requirements place demands on mechanical design of the vane positioning mechan which, unless adequately met, reduce the effectiveness proper choice of vane size and material according to the t requirement.

The attenuator described in this note was developed a view to providing an alternative mechanical arrangem to that described above. A diagram of the attenuator shown in Fig. 1. A flexible resistive vane is "bowed," means of a micrometer screw mechanism, into the centr the guide to increase the attenuation. It will be noted in this arrangement the lead screw is effectively shielded

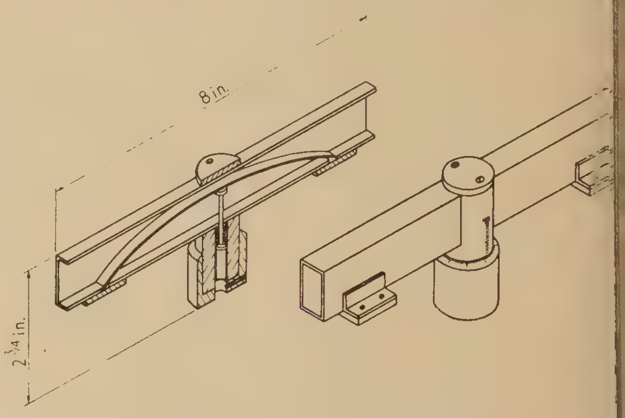


Fig. 1. Sectional and assembled views of attenuator

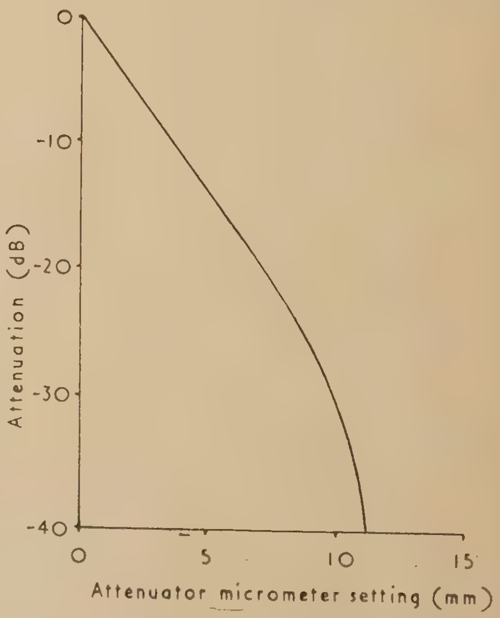


Fig. 2. Attenuation characteristic

vane itself, so that reflexions from this cause are not ountered, moreover as the ends of the vane are located weak field region (namely, the narrow face of the guide), vane need not be tapered. The ends of the vane slide in narrow face slots of the guide; the length of the vane is, refore, slightly longer than the distance between the slots order to maintain the location of the vane as the bowing ncreased. The three-point location of the vane also assists maintaining the short axis of the vane perpendicular to broad face of the guide.

xperimental results show that the attenuator has good rowave characteristics. A calibration curve for the enuator (frequency 9250 Mc/s) is shown in Fig. 2; it may noted that over a range of approximately 20 dB the enuation is linear with the micrometer setting, but that as vane approaches the centre of the guide the attenuation reases more rapidly. Through the attenuation range, the tage standing wave ratio at the input to the attenuator, ich was terminated in a matched thermistor load section the measurement of power, did not exceed 1·07 (in the ence of the attenuator, the voltage standing wave ratio at input of the thermistor section was 1·05).

he writer wishes to acknowledge the assistance of Mr. E. ider during the course of the development work, which s undertaken at the University of Adelaide, South Australia.

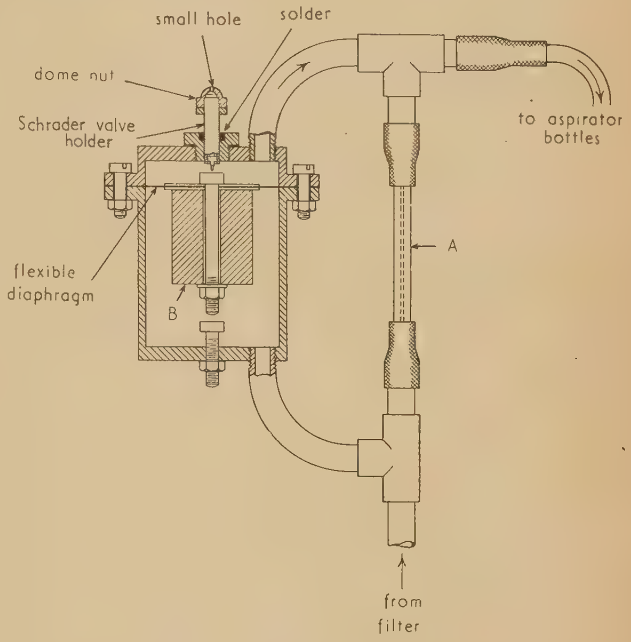
gulator for maintaining a constant gas flow through a restriction of variable resistance

y E. F. Keen and P. L. Palmer, B.Sc., Fuel Research Station, London, S.E.10

[*Note received* 12 *April*, 1956]

amount of solid matter in air or flue gas is usually ermined by aspirating a constant stream of the gas through lter by means of a small vacuum pump. As solid matter ects on the filter the resistance increases and frequent ustment is required to maintain the rate of flow constant. automatic controller, described in this note, is designed give a constant flow under such conditions. It is con-cted of stainless steel with a glass capillary tube, and a ible diaphragm of polyvinyl chloride sheet, 0·01 in. thick. he vacuum pump draws gas through the filter by way of capillary tube *A* (see figure) and air is allowed to leak the pump through a Schrader valve. The rate of flow ough the filter is regulated by this air leak.

hen the flow of gas is at the correct rate the pressure erence across the capillary tube *A*, which is also the pressure erence across the thin flexible diaphragm to which the ght *B* is attached, is such that it just supports the weight *B*. light decrease in this pressure difference consequent upon ecreased rate of flow through *A* will cause *B* to fall and e the Schrader valve, thereby reducing the bleed on the ip until the flow rate through the flow meter returns to its inal value and *B* again rises. Ideally, in operation, a ic equilibrium would soon be established in which the e is held sufficiently open to maintain the desired rate of . In fact, owing to the pulsating nature of the vacuum duced by the type of pump used, the equilibrium estab-ed is dynamic, which is still satisfactory but may some-s lead to chatter unless some means of smoothing the flow is introduced between the device and the pump. 500 ml. aspirator bottles (not shown), connected by ns of a short length of capillary tube, constitute an effective way of producing this smoothing. The additional pressure loss caused by this smoothing system need not be large; adequate smoothing was obtained with a capillary tube which caused pressure losses of 0·22 in. and 0·56 in. of mercury at rates of flow of 1 and 2 ft³/h respectively. Similarly, by suitable choice of the value of the weight *B*, the pressure lost in the flow meter *A* may be kept below ½ in. of mercury. Any desired rate of controlled flow within the capacity of the pump may then be selected simply by substituting various other suitable capillary restrictions for the capillary tube *A*.



Regulator for maintaining a constant gas flow

It was considered that when the Schrader valve was screwed into its standard holder the spring of the valve was compressed more than was necessary and might cause excessive wear of the valve. Hence the top of the valve holder was cut off and a perforated screwed retaining cap and lock nut fitted so that the compression of the spring could be adjusted as required. It was found that very little compression was required; if the inside of the holder does not touch the moving part of the valve, its own weight is sufficient to ensure satisfactory working.

The effectiveness of the control may be seen from the table which shows the rate of flow obtained both with and without the use of the regulator for various differential pressures produced by the restriction due to the filter. In the tests on the variation in flow rate without using the regulator, the required rate was set by inserting a ballast restriction in the flow circuit and having no bleed, a condition of working which should produce the greatest attainable stability of the flow rate.

Flow rate without regulator		*Flow rate with regulator*	
Pressure across filter (in. w.g.)	*Flow rate* (ft³/h)	*Pressure across filter* (in. w.g.)	*Flow rate* (ft³/h)
0·6	0·99	0·5	1·04
3·3	0·87	2·8	1·04
7·7	0·76	6·8	1·02
13·4	0·65	12·0	1·01
19·7	0·49	20·2	0·97

The valve should have a long life but this will depend on the nature of the gases being aspirated; it is not a very important consideration on account of the ready availability of Schrader valves and the ease with which they may be replaced.

This note describes apparatus developed for the programme of the Fuel Research Board of the Department of Scientific and Industrial Research and is published by permission of the Director of Fuel Research. The illustration is Crown Copyright and is reproduced by permission of the Controller of H.M. Stationery Office.

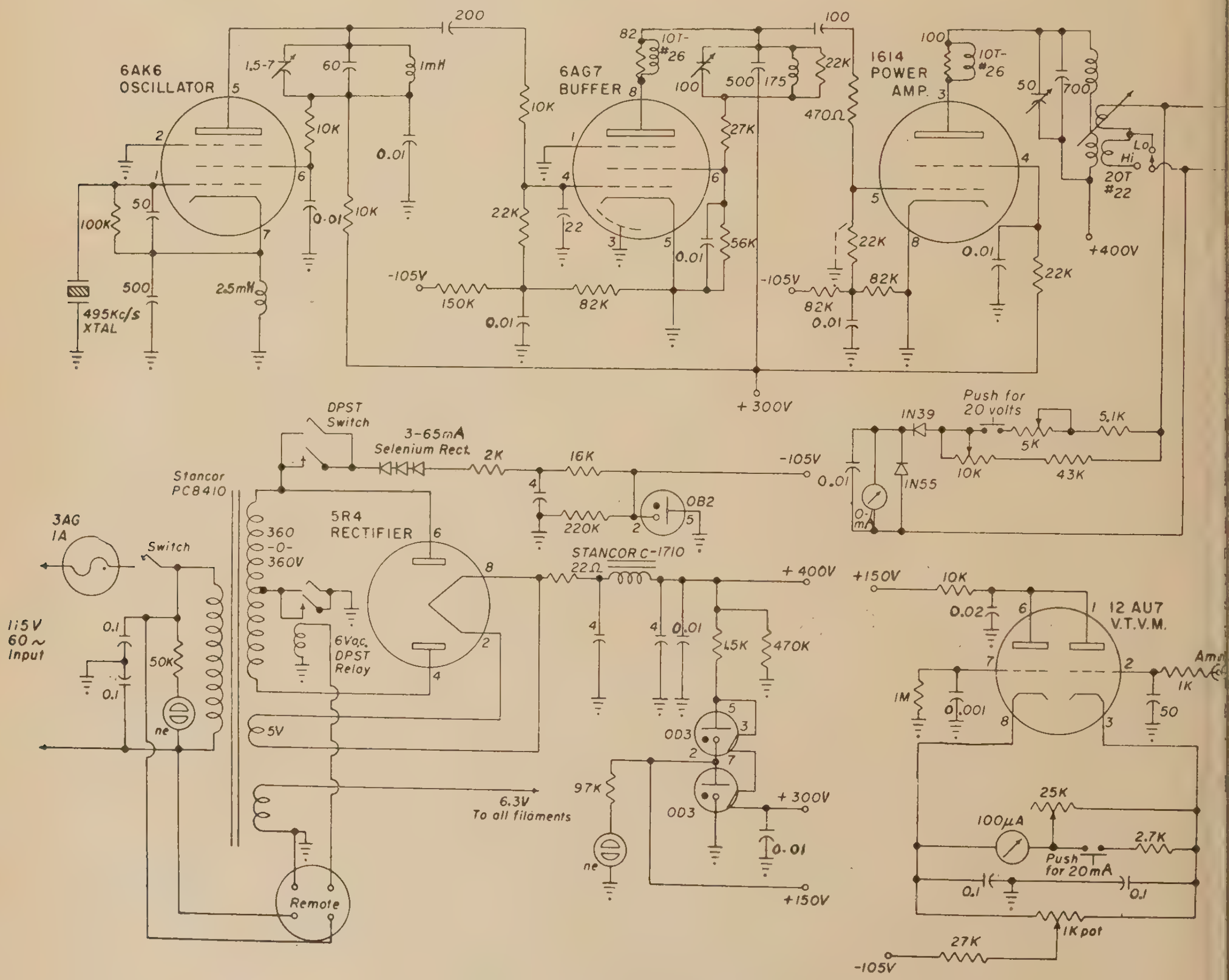
An apparatus for the production of controlled lesions in biological tissue without stimulation

By G. E. Kaufer, M.Sc., National Institute of Mental Health, Bethesda, Maryland, U.S.A.

[*Note received* 2 *May*, 1956]

A fruitful means of investigating the form and function of the central nervous system, the method of localized destruction of tissue, can be used to its fullest advantage only if the size and shape, as well as position, of the resulting lesions can be controlled. To fulfil the need of an instrument which would enable the operator to uniformly coagulate tissue wit stimulating attendant areas, a radio-frequency gene adopted for physiological use was evolved. Lesion siz be predicted in advance within certain limits if the fact time and power are kept low and within narrow bo Even under extreme conditions, irregularities of the l periphery are fewer than would be obtained with a c current source of energy. Both monopolar and bi coagulation can be performed and large areas of tissue be destroyed by multiple electrode placement. Further extremely small uniform lesions (fractions of a millimet length) can be produced, minimizing shock effects reducing the incidence of mortality in experim animals.

The radio-frequency coagulator evolved is a compilati standard high frequency and related circuitry (see the fi into a compact package which will perform the nece functions required of such an instrument. Consisting fixed 500 kc/s master oscillator, buffer, power amplifier associated power supply, the unit contains such desi features as: variable output voltage from 3–100 V r.m.s selection of optimum coagulation time and current; range ammeter and voltmeter for continuous monitorin the output; symmetrical output waveform with low har content; low output impedance under normal oper


6AK6
OSCILLATOR
1.5-7
60
ImH
200
10K
0.01
100K
50
500
495Kc/s
XTAL
2.5mH
6AG7
BUFFER
22K
22
-105V
150K
82K
56K
27K
0.01
82
10T-
#26
100
500
175
22K
470Ω
1614
POWER
AMP.
10T-
#26
50
700
Lo
Hi
20T
#22
+400V
22K
82K
-105V
82K
0.01
+300V
DPST
Switch
3-65mA
Selenium Rect.
2K
16K
-105V
0.01
IN39
Push for
20 volts
5.1K
5K
10K
43K
IN55
0-1
mA
Stancor
PC8410
3AG
1A
Switch
115V
60 ~
Input
0.1
50K
ne
360
-0-
360V
5R4
RECTIFIER
6Vac.
DPST
Relay
5V
220K
OB2
STANCOR C-1710
22Ω
+400V
+150V
10K
15K
470K
0.01
OD3
97K
ne
6.3V
To all filaments
+300V
+150V
Remote
0.02
12 AU7
V.T.V.M.
1M
.001
50
1K
25K
100μA
2.7K
Push
for 20mA
0.1
27K
1K pot
-105V

Circuit diagram of radio-frequency coagulator nditions to prevent slight changes in tissue resistance from ecting the magnitude of the applied current and potential; lity to withstand overloads or even momentary short-cuiting of the electrodes without damaging components or errupting the functioning of the device; and a non-critical cuit which readily lends itself to rapid duplication with od prospect of obtaining the desired result. The generated lio frequency is fed *via* a coaxial cable to the electrodes a terminal box mounted directly on the stereotaxic trument.

crystal oscillator was chosen for purposes of reliability l ease of maintaining tuning of subsequent stages due to nimum oscillator drift. A higher frequency (greater than Mc/s) would be better from the biological standpoint* that the impedance of tissue remains more nearly constant ring stimulation and at rest at this higher wavelength. On other hand, high frequencies present more of a problem transmission owing to capacitive leakage currents and are re prone to cause interference with radio channels. The e 6AG7 buffer stage acts as an isolating device between illator and power amplifier, preserving the output wave-pe as well as greatly improving the regulation and stability the unit. A plate circuit parasitic suppressor is included a precautionary measure and the plate tank is purposely ded with a 22 kΩ resistor to make tuning less critical. e final stage employs a beam power tube with high plate ential for sufficient undistorted output. The high-C plate k keeps the harmonic content to a low value and a vari-upler (rotating link) is used to extract a continuously iable output voltage at low output impedance. The dual ge monitoring voltmeter employs two types of efficient stal diodes for rectification, selected so that their peak erse voltage ratings are not exceeded. Most high frequency meter circuits employ thermocouple elements† for con-sion of the fluctuating current into the unidirectional tage necessary to actuate a D'Arsonval type meter. The jor disadvantage of such an instrument is its inability to hstand overload without danger of burning out. Since ctrode spacing during coagulation may be very small l the possibility of short-circuiting is great, a current nitoring system which would perform satisfactorily under h conditions is warranted. Furthermore, it is difficult to nge ranges on a thermocouple meter and the indicating le is very non-linear, necessitating three or even four ges to encompass the scope of currents employed. A rent transformer and rectifier housed in the terminal box, l vacuum tube voltmeter circuit overcomes all of these advantages. Because of the coagulator's stringent require-nts, its power supply is called upon to furnish four erating voltages in addition to the filament potential. The ical potentials are regulated to minimize radio-frequency plitude drift and stabilize the operation of the device. The ire coagulator is housed in a 20 × 10 × 9 in. cabinet, with ged top cover.

esion sizes, ranging from those produced mechanically by electrodes to a volume of over 20 mm^3 have been produced h this apparatus, the first model of which has been in since December, 1954.

McClendon, J. F. *Amer. J. Physiology*, **82**, pp. 525–32 (1927).

Terman, F. E., and Pettit, J. M. *Electronic Measurements.* ed., pp. 9–15 (New York: McGraw-Hill Book Co. Inc., 1952).

The output resistance of a switch-dial potential divider

By R. W. Williams, The English Electric Co. Ltd., Stevenage, Herts

[*Note received* 6 *July*, 1956]

There are occasions when knowledge of the output resistance of a switch-dial potential divider is of some importance, for example in the estimation of the loading errors which may arise when a divider of this type is used in analogue computing applications. The table below gives the output resistance of three kinds of divider—the well-known Feussner and Varley types, and the new design described recently in this *Journal* by Clothier.* The output resistance is defined as the resistance between the potential terminal and the two input terminals connected together. For simplicity, but without serious loss of generality, a two-dial decade divider is assumed in each case, its setting being "0.xy" where x and y are integers lying within the ranges 0–9 and 0–10 respectively. The output resistance is expressed as a fraction of the total resistance of the divider.

Output resistance as a function of divider setting

Divider	*Output resistance*
Feussner	$(100y - y^2 - 20xy + 1000x - 100x^2) \times 10^{-4}$
Varley	$(200y - 11y^2 - 20xy + 1000x - 100x^2) \times 10^{-4}$
Clothier	$(1000y - 91y^2 - 20xy + 1000x - 100x^2) \times 10^{-4}$

It is clear from the table that the Varley divider does not differ greatly from the Feussner in its output resistance, although the difference is great enough to warrant a reminder to users that the equivalent circuit of the Varley is not that of a simple potentiometer. The Clothier divider exhibits a rather severe variation of internal resistance with its setting. As an example, its output resistance, which is 0·2500 of the total resistance at a setting of 0·50, becomes 0·4725 at 0·55, and reduces to 0·2400 at 0·60.

* Clothier, W. K. *J. Sci. Instrum.*, **33**, p. 196 (1956).

A method of storing mechanically fragile specimens for examination

By C. A. Tremlett, B.Sc., Grad.I.E.E., M.-O. Valve Co. Ltd. at The General Electric Co. Ltd., Wembley, Middlesex

[*Note received* 30 *July*, 1956]

In carrying out a preliminary examination of a fragile filament from a large transmitting valve, it was found that the structure would need to be transported some distance by road. This would normally be quite a hazardous procedure even if great care were employed. The problem has been overcome by lowering the filament into a glass vessel filled with hot gelatine solution mixed in the proportion of four parts water to one of gelatine by weight. When set, the structure, in addition to being quite easily transportable, may be photographed through the transparent jelly. The extraction of portions for section may be carried out easily, the remainder of the filament remaining in its correct geometric position. Should the period of storage be more than a few days, precautions have to be taken to prevent the jelly from shrinking. This technique might, it is thought, have quite wide application.

New books

X-rays; their origin, dosage and practical application. 7th ed. By W. E. SCHALL. (Bristol: John Wright and Sons Ltd., 1956.) Pp. vii + 331. Price 42*s*.

There can be but few scientific or technological textbooks that attain the distinctions of a seventh edition and useful service as standard texts for more than thirty years in a rapidly expanding subject. This book has achieved these merits through its author's rare insight into the interests of those on whose practical skill, knowledge and reliability depends the operation of equipment and methods in our progressing scientific age. For in the training of technologists a middle course should be steered between the dangers of encouraging unintelligent button-pushing and too profound scientific appreciation.

The reviewer feels this book strikes the right balance. Throughout the author has chosen and explained his topics well. Furthermore, the claim seems justified that the book caters for all radiographers whether they be concerned with diagnostic, therapeutic or industrial applications. Those concerned with routine X-ray diffraction tests would benefit equally.

The book is well produced and therefore a pleasure to read, particularly owing to excellent figures and plates. There are, however, some striking exceptions, notably Fig. 169 on which the writing can barely be read. A uniform presentation of circuit diagrams would be helpful (e.g. compare Figs. 95 and 100).

The reviewer regrets the omission of literature references. Mention of original papers may be out of place, but encouragement for looking up the writings of other authors in wider and more specialized fields is so fundamental in the training of scientists and technologists that suggestions for further reading should have been included.

Nevertheless, further generations of radiographers will yet praise and thank author and publisher for this fine and useful volume.

H. S. PEISER

Actes du 2^e congres international de photographie et cinematographie ultra-rapides (Paris, September, 1954). Edited by P. NASLIN and J. VIVIE. (Paris: Dunod, 1956.) Pp. xxvii + 455. Price 6000*f*.

It is a pleasure to review a book which has been so well edited and published. At the second international congress on high-speed photography sixty-eight papers were presented on techniques of high-speed photography and applications in many branches of science. Twenty of the papers were given in English, thirty-three in French, and fifteen in German. The papers have been printed in the language in which they are presented, but in addition abstracts have been given in English, French and German for each paper, and the legends for all illustrations have been given in the three languages, so that this work of reference is much more convenient to consult than the collected works of most international conferences. It would be a great help if this practice were more widely adopted.

The papers have been extensively illustrated by some 650 figures and diagrams, including a number of excellent colour pictures. Many of these are half or full plates comprising a whole sequence of frames, so that the total number of pictures is in the thousands. The proceedings form an impressive illustration of the importance of high-speed photographic techniques in fields as widely separated as ballistics, biology, fluid dynamics, arc-welding, combustion, impact, mech engineering, metallurgy, fracture, dynamic stressing, atc tion, micrography and radiography.

It is significant, too, that the techniques of high- photography are required not only for the study of which are customarily thought of as fast, but are ju necessary in the fine analysis of relatively slow pro when these are observed under high magnification, a exposure times there must be made briefer in proporti the magnification is increased. As has been said i foreword, any event if observed on a sufficiently small becomes a subject for high-speed photography.

The techniques for studying such varied fields are extended very rapidly. Rates of taking pictures, methc synchronization, methods of lighting, new mechanica inertialess shutters, new types of camera, new generators, improvements in mechanical and optical ponents, and in interferometric, schlieren and other o systems, are all advancing at a surprising rate. The con was of great value to the several hundred people who atte and the thanks of research workers in an increasingly circle are due to those who helped to organize it and t editors of the proceedings; in particular to Prof. P. N who has done so much to collect and present this exte survey of new techniques of analysis in so wide a ran researches.

J. S. COURTNEY-PR

Aberrations of thin lenses. By H. H. EMSLEY. (Lo Constable and Co. Ltd., 1956.) Pp. xvi + 352. 50*s*.

In his preface the author states that his purpose in w this book is that it may be useful to technicians and execu who occasionally use and possibly need to design o systems, but have no wish to become lens designers, and it will be of service to students by filling the gap betwee elementary and more advanced treatises on optical d The latter aim is well fulfilled, particularly since num exercises are set throughout the book, but the reviewer that the technician or executive who has no desire to be a lens designer would have to be very stout hearted to mence even the thin lens design of a system he requ unless of course he found in Mr. Emsley's book a sy which was similar to the one he had in mind. This com is in no way a reflexion on the author whose clarity l nothing to be desired; before one can indulge in the sim designing one has to have a certain familiarity with conventions and variables, and it is useful to have a m picture of the physical meaning of aberration equa before one can manipulate them easily, the acquisitio which takes time and the reading throughout of such a as that under review. One must have more than a pa interest in the subject to take these steps.

The first seven chapters cover roughly the same grou that covered in Conrady's *Applied optics and optical* and the treatment and nomenclature are roughly the s Chapters 8 and 9 deal with spherical and astigmatic spec lenses but contact lenses are purposely omitted. The ends with a useful chapter on the distribution of lig optical instruments, a branch of optics which is rarely cussed in books on optical design.

The book is remarkably free from errors but excep must be taken to the description of coma on p. 163

. 6.6. In a comatic image rays from an annular zone of optical system intersect the ideal image plane in a circle. :orrect description of coma has been given by Kingslake* l others.

J. L. HOUGHTON

---

trument engineering, Vol. 3, Part 1. By C. S. DRAPER, W. McKAY and S. LEES. (London: McGraw-Hill Publishing Co. Ltd., 1955.) Pp. xxviii + 875. Price £6 11*s*. 6*d*.

is volume of nearly 900 pages is an example of the American tbook on the grand scale, in which separate chapters are tten by specialist authors who deal exhaustively with their pective subjects. The treatment throughout follows a dly logical plan, careful attention being given to definitions l the explanation of basic concepts. Extensive use is de of functional block diagrams, and if in some instances breakdown appears excessively detailed, it encourages a ınd analytical approach. The use of non-dimensional iables for the presentation of information in equations l curves is a most useful form of condensation, showing the greatest advantage in the chapter on vibration. In t the book is a mine of valuable information and data, ose wealth is probably readily accessible to those familiar h the idiom employed. Whether it will be found useful, he preface suggests, as "a self-contained text and reference ok on measuring instruments and systems" to readers on s side of the Atlantic, will depend on their ability to cope h the presentation, particularly with the extensive use of -defining symbols which, on short acquaintance, your iewer found cumbersome and irritating.

Although theoretical work from Vols. 1 and 2 is repeated clarification, this does not justify the claim that this ume is self-contained. It has but eight chapters, of ich two deal with definitions and basic concepts. The naining six are entitled: Elements and components asso- ted with instrument systems; Temperature-measuring truments; Electromechanical measuring instruments; ssure-measuring systems; Integrators and differentiators; ration measurement and vibration isolation. Thus, hough these chapters are of wide scope, important issions are obvious. Nevertheless, it is a valuable work, l although the writer would not consider it a worthwhile estment on his own account, he would be glad to have ess to it in company with the two preceding volumes.

E. B. MOSS

---

ines Handbuch Technischer Regelvorgänge. By W. OPPELT. (Weinheim: Verlag-Chemie, 1956.) Pp. 555. Price DM 36.40.

e aim of this book, as stated by the author, is to give a vey of closed loop control techniques guiding the reader a medium level of understanding and using mathematics ly sparingly. The predominant tool used throughout is respondingly graphical demonstration of component and tem behaviour.

The intention to give a broad survey rather than a detailed entific account marks the outstanding features of this book ich distinguish it from the classical publications available the subject: it accentuates a "horizontal" accumulation of ormation within the "vertical" build-up of the subject. e latter is much in line with similar works on closed loop ntrol.

The object of the book is first demonstrated by simple examples followed by an introduction into the mathematical tools used for deriving and converting transfer functions, frequency response and transient response characteristics. Laplace transform is briefly mentioned but not used.

After a discussion of many practical types of controllers and regulators the author returns with the transition to the closed loop system again to a more mathematical treatment of criteria of stability, degree of stability and the methods of derivation of the complex roots of a characteristic equation of higher order including the root locus method. Sections on means for influencing the performance by the choice of regulator systems, of phase shifting networks, feed-back and optimization are followed by discussions of interlinked multiple loop control systems, of the introduction of compensating signals from independent variables and of systems subjected to more than one regulating condition. Separate sections deal with non-linear systems and with relay control systems. The use of model circuits, simulators and calculating machines is briefly outlined.

The concluding section is called "Atlas of simple closed loop control functions." It gives in thirty-five one-page charts a classified survey of the behaviour of a number of basic combinations of regulator and controller functions by showing frequency response locus, transient response and open loop response to external disturbances obtainable in each case. It seems a pity that numerical data to which individual curves refer have been omitted in this section.

The book (which appears to have been intended to be read particularly also by chemical engineers) will be most welcome to readers who wish to enlarge their knowledge particularly about control elements developed in fields different from their own and about approximating methods of system analysis which were developed abroad. Illustrations are excellent and contribute outstandingly to the clarity of the book. It is, however, unavoidable that there is ample margin left for hard work to be done by the reader who wants to rise to a full understanding of many details involved.

E. FRIEDLANDER

Handbook of meteorological instruments. Part 1. (London: H.M. Stationery Office, 1956.) Pp. x + 458. Price 45*s*.

The Instruments Division of the Meteorological Office has made a splendid start to its production of a comprehensive handbook on the design, installation, operation and maintenance of all instruments used at Meteorological Office stations. The main chapters are on: pressure; temperature; humidity; wind; precipitation; evaporation; sunshine, starshine, and radiation; visibility; cloud; and marine observations.

Though the emphasis is on standard instruments there is a lot of useful information about special instruments for research, and as the book is liberally supplied with good photographs and excellent line drawings it could be used as a source of ready-made material for teaching and textbooks.

The method of compilation has led to a little too much repetition of instructions about components common to many instruments, and there are a few minor blemishes (e.g. the last column of Table 5 implies that 1° F is 9/5 of 1° C; Plate 13 is almost illegible; in Chapter 5 the density of air is wrong by a factor of 1000).

The book is designed for use within the Office but many others will get full value for money, particularly those who are interested in the physics of instruments, those who have to make physical measurements out-of-doors and those who have to advise others on such measurements.

H. L. PENMAN

---

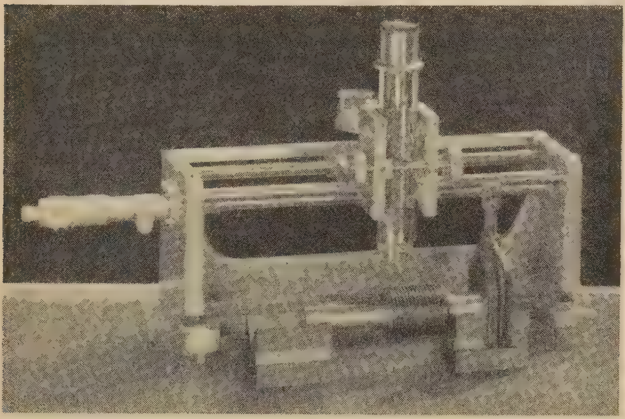
* KINGSLAKE, R. The diffraction structure of the elementary na image. *Proc. Phys. Soc.* [*London*], **61**, pp. 147–158 (1948).

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or imp products. The Institute of Physics assumes no responsibility for the statements given below: information for these has taken from literature supplied.

Vernier microscope. James Swift and Son Ltd., 113–115a Camberwell Road, London, S.E.5.

The Utilex vernier microscope is capable of both linear and angular measurement. The viewing and measuring unit of the instrument is mounted within a robust steel casting which is webbed to give the maximum rigidity between the end plates, the base and the microscope carriage supports. Steel toes are fitted to the casting so that it may be stood upon one end or upon two of the sides, and the base of the casting is slotted for the insertion of a plate-glass stage, $\frac{1}{4}$ in. thick, measuring 11 × 3 in. approximately, which can be clamped in position by means of fibre-padded knurled screws. The free end of the casting is drilled so that the instrument can be mounted vertically upon a tripod or vertical pillar. The sliding carriage carries a vernier scale which butts against a graduated bar running the full length of the instrument. The microscope carriage slides freely over a steel rod which is spring-loaded, *via* a thrust bearing against a Moore and Wright micrometer screw fitted with a calibrated drum which is mounted on one end of the casting.



Vernier microscope

The microscope body accepts any objective or eyepiece of standard R.M.S. specification, such as are used with ordinary microscopes. Cross-lined, protractor and measuring graticules can be supplied for insertion in the eyepieces, and the standard eyepieces can be replaced by special goniometer and filar micrometer eyepieces. The instrument is available for English or metric measurement and the full movement of the microscope carriage is over a graduated distance of 8 in. or 200 mm.

Two-axis electrical recorder. Frathom Co. Inc., 33 West 42nd Street, New York 36, U.S.A.

The Moseley model 3 Autograf is an instrument for desk-top use and is intended for rapid and accurate graphical recording of two variables. Independent, self-balancing servo-systems actuate a drafting machine type of mechanism, which traces Cartesian co-ordinate curves on standard $8\frac{1}{2} \times 11$ in. graph paper from any data that can be reduced to electrical form. The fully exposed recording table permits observations of the entire curve being drawn. The sensitivity is 5 mV for the x-axis and 3·5 mV for the y-axis, with ten additional ranges up to 500 V for the x-axis and 350 V for the y-axis. input resistance is given as 200 kΩ/V on ranges up to and 2 MΩ/V on all higher ranges. The accuracy resolution are stated to be 0·25%.

Dispersion meter. Doran Instrument Co. Ltd., Stroud,

The model 2 dispersion meter has been designed to pr a direct measurement of the dielectric dispersion of insulation of electrical equipment, or of samples of insul materials. It has been found that this quantity is suitabl assessing the moisture content of paper insulation and of many other materials when it is made over a frequ range of about 0·5 to 50 c/s. The test is then sensitive absolute, in the sense that dry materials have zero disper In the meter illustrated in the figure, the quantity meas D, is defined by

$$D = (C_2 - C_1)/C_1$$

where C_1 is the instantaneous capacitance 3·18 ms applying the charging voltage and C_2 is the instantan capacitance after 318 ms. The measurement is mad applying to the specimen a rectangular pulse of char voltage having a duration of 318 ms. This is immedi followed by a short-circuiting pulse of 3·18 ms dura The specimen is then isolated and the recovery volta measured by a valve voltmeter. The dispersion is then g by

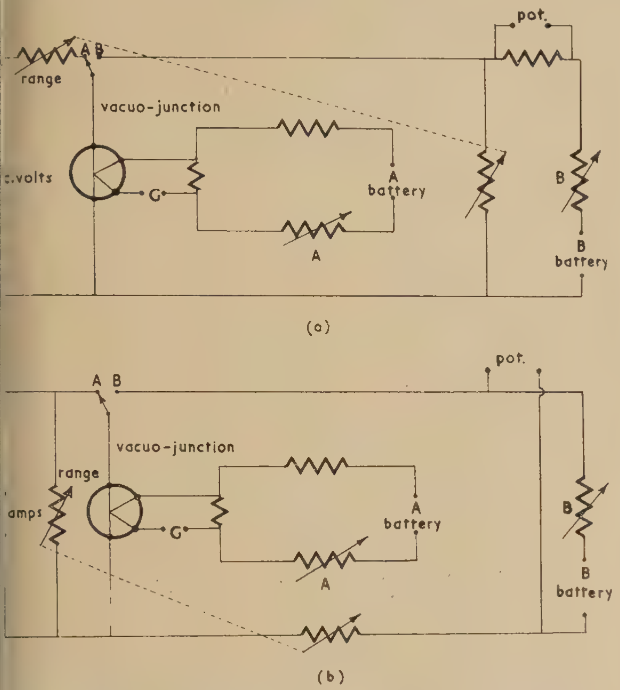
$$D = V_1/(V_0 - V_1)$$

where V_0 is the charging voltage and V_1 is the reco voltage. Equation (2) is used to provide a scale on the meter reading directly in dispersion. In practice, owin the continued increase in instantaneous capacitance periods greater than 318 ms, the recovery voltage rises peak and then slowly decays. The dispersion is taken as value corresponding to the peak of the recovery voltage.

Dispersion meter

A.C.–D.C. converter. Croydon Precision Instrument 116 Windmill Road, Croydon, Surrey.

This instrument is claimed to measure alternating curr and voltages over a frequency range of 25 c/s to 10 kc/s an accuracy of 0·05%. It is used in conjunction wit precision vernier potentiometer. The basis of the instrum is a vacuum thermojunction which is calibrated on d.c.; calibration can then be used for a.c. The figure shows arrangement of the instrument circuits for both voltage current measurements. The principle of operation is t th the two-way switch in position *A*, a portion of the a.c. oply to be measured is passed through the heater of the ıction and the resulting e.m.f. from the thermocouple is lanced against an internal auxiliary potentiometer by ans of the variable resistance *A*. The two-way switch is

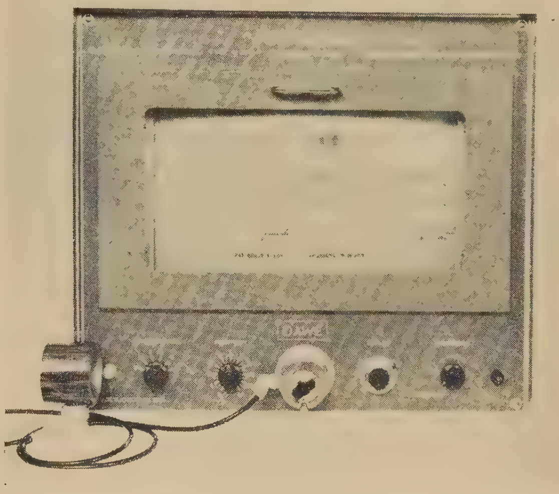


Basic circuit diagrams of a.c.–d.c. converter when used (*a*) for potential, (*b*) for current measurement

en moved to position *B* and the junction heater is heated a d.c. supply, adjusted by the variable resistance *B*, until e e.m.f. from the thermocouple is exactly the same as in e first part of the experiment. A portion of the d.c. supply then measured by a separate precision potentiometer con-cted to the points indicated. By means of the range switch, ıich controls the two resistances indicated in the figure, the strument can be set to cover voltage ranges of 7·5, 15, 30, , 150 or 300 V and current ranges of 18, 35, 60, 110, 250, 0, 1000, 2500 or 5000 mA.

ltrasonic thickness gauge. Dawe Instruments Ltd., 99 Uxbridge Road, Ealing, London, W.5.

n instrument known as the Visigauge type 1108 measures e thickness of material from one side by determining the ndamental natural frequency of vibration in the thickness rection. The thickness is indicated directly on a calibrated ale of a 21 in. cathode-ray tube. The figure shows the neral appearance of the instrument. A crystal transducer energized by a radio-frequency oscillator and the ultrasonic brations produced are coupled to the material under test a thin film of oil or grease. These vibrations pass through e material and are reflected from the opposite surface. At rtain frequencies, the wavelength of the vibrations sets up anding waves in the thickness direction. When this reson-ıce occurs, extra power is drawn from the oscillator. The ickness is directly indicated on the cathode-ray tube screen frequency modulating the oscillator with the time-base eep. Distance along the time-base trace is therefore pro-ortional to frequency and the horizontal scale can be librated directly in thickness. As the frequency passes through the fundamental resonance value, the pulse of extra power taken from the oscillator is amplified and used to produce a vertical trace on the cathode-ray tube at a position corresponding to the resonance frequency. Interchangeable scales directly calibrated in thickness to suit the oscillator range and material under test, are placed in front of the cathode-ray tube screen. The range of thickness which can be measured is about 0·005 to 2·5 in. The accuracy depends on the particular application, and varies from 0·1 to 2%.



Ultrasonic thickness gauge

Zirconate pressure transducer. Atlantic Research Corporation, Alexandria, Virginia, U.S.A.

A pencil-shaped transducer (illustrated in the figure) utilizes a lead zirconate ceramic as the piezoelectric element. The transducer is intended for making free-field pressure-time recordings of sound or shock waves produced by explosions, passing missiles, engine noise or other sources. The sensitivity of the instrument is stated to be 0·4 V per lb/in.^{2} on open circuit, and to be constant within 5% over the temperature range −20 to +60° C. The frequency response is stated to be constant within ±2 dB over the range 1 c/s to 80 kc/s.

Lead zirconate pressure transducer

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics.

Fellows: C. B. Abbott, C. E. Arreger, J. B. Dick, P. W. Mummery, B. N. Watts.

Associates: S. G. G. Aston, K. D. Barritt, K. M. Beazley, J. Blitz, G. R. Boulding, D. O. Bullas, W. Burnside, P. B. Carter, K. J. Close, R. F. Coe, F. C. W. Colmer, T. C. Common, R. H. Davies, M. De, A. S. Douglas, J. Gilbert, A. Gray, G. Y. Haig, B. I. H. Hall, F. W. Harrison, P. W. Hoare, T. A. Holbeche, J. T. Jefferies, P. Johnson, B. E. Jones, T. B. Kent, W. A. Langton, J. H. Leck, C. H. Leigh-Dugmore, W. J. Legon, J. G. Moreley, G. H. Parks, I. J. W. Pothecary, K. Pringle, D. A. Secomb, K. G. Stephens, A. F. Taylor, R. G. S. Taylor, R. J. Tracey, F. L. Ward, P. G. Walker, J. Wartnaby, J. W. Watts, A. N. D. Young.

Forty-seven Graduates, eight Students and five Subscribers were also elected.

Journal of Fluid Mechanics

A new periodical has been established to publish "theoretical and experimental investigations of all aspects of the mechanics of fluids and is to be in six parts per volume" under the title *Journal of Fluid Mechanics*. The first issue runs to 128 pages measuring $6\frac{3}{4} \times 10$ in. and contains the following papers: The slender elliptic cone as a model for non-linear supersonic flow theory, by M. D. van Dyke; On the collision of drops in turbulent clouds, by P. G. Saffman and J. S. Turner; Drift, by M. J. Lighthill; On the thrust due to an air jet flowing from a wing placed in a wind tunnel, by L. C. Woods; Vibrational relaxation in oxygen and nitrogen, by V. Blackman; Long waves on a rotating earth in the presence of a semi-infinite boundary, by J. Crease; The laminar boundary layer on oscillating plates and cylinders, by M. B. Glauert; Diffraction of a weak shock with vortex generation, by Nicholas Rott.

The new journal, which is printed and published by Taylor and Francis Ltd., of Red Lion Court, Fleet Street, London, E.C.4, is edited by Dr. G. K. Batchelor of the Cavendish Laboratory, Cambridge.

The subscription price per volume is £5 10*s*. 0*d* ($16.50 in U.S.A., Canada).

Exhibition of instrumentation

An exhibition devoted to laboratory and industrial instruments will be held at Olympia, London, from 7–17 May, 1957. During this period it is also intended to have an extensive programme of lectures and meetings. This "Instruments, Electronics and Automation Exhibition" is being promoted by five trade associations and arranged by Industrial Exhibitions Ltd., 105–106 New Bond Street, London, W.1, from whom further details may be obtained.

Publication of patents abridgements

The volumes containing abridgements of the p specifications accepted during the war years are now on There is a complete range of volumes up to and inclu the 640,001–660,000 series which contains specifica accepted and published prior to November 1951. Abr ments of specifications accepted and published prio August 1955 are also on sale in sheet form.

The abridgements in bound and sheet form can be obta from the Sale Branch, Patent Office, 25 Southampton B ings, Chancery Lane, London, W.C.2, at prices varying f £1 1*s*. 0*d*. to £1 10*s*. 0*d*. per group.

Journal of Scientific Instruments

Original contributions accepted for publication in future i of this Journal

The generation of accurate cylinders. By D. A. Davies.
An automatic analyser of uranium content in process streams. By H L. H. Brown and D. R. Chapman.
A simple direction-sensitive phototransistor circuit for use in optica counting systems. By W. T. Bane and D. L. A. Barber.
Operation of a diffusion cloud chamber with 23 atm of deuterium. By Batson, B. B. Culwick, H. B. Klepp and L. Riddiford.
A linear, temperature compensated hot wire anemometer. By E. L. Deac D. R. Samuel.
A sensitive photoelectric polarimeter. By B. R. Malcolm and A. Elliott.
Temperature cycle controller. By J. C. Barnes.
Measurement of the optical density of smoke in a chimney. By A. Littlewo
A mechanical Gardner mobilometer. By J. E. Roberts, A. J. Taylor and Woods.
A portable ionization current comparator. By L. A. W. Kemp and B. J. Be
Experimental investigations of the dead time of univibrators. By D. Kisi J. Szivek.
A constant-current device for use in the measurement of transference nu by the moving boundary method. By D. T. Hopkins and A. K. Covin
A double-beam microspectrometer. By G. H. Haggis.
Precision measurement of small radii of curvature. By R. N. Wilson.
Measurement of high viscosities by shearing between parallel plates. By Humphreys and N. Stone.
Two optical instruments used in semiconductor research. By D. G. Avery.
Contrast arising from elastic and inelastic scattering in the electron micro By M. E. Haine.

British Journal of Applied Physics

Contents of the November issue

CONFERENCE REPORT

Summarized proceedings of a conference on the structures of semi-crystallin non-crystalline materials—London. November 1955. By R. E. Frankli R. L. Gordon.

ORIGINAL CONTRIBUTIONS

The suppression of screen grid emission by carbon. By J. A. Champion.
Multiplicity in the anode marks of sparks. By J. M. Somerville and Grainger.
The frequency of vibration and the elastic stability of a fixed-free strip R. F. S. Hearmon.
The fusing of wires with heavy surge currents. By A. E. Barrington.
The electric strength of hydrocarbon gases. By A. E. D. Heylen and T. J. L
Reduction of counting time in low activity assays. By H. A. Hughes.
The tensile strengths of viscous liquids under dynamic loading. By T. H. B

NOTES AND NEWS

Correspondence

A photoelastic method of two-dimensional separation of stresses along a li symmetry by using the isochromatic fringes only. From P. D. Flynn R. Guernsey; S. P. Christodoulides.
Ring conduction in the early stages of sparks. From J. M. Somerville and Fletcher.

New books
Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation o contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicatio from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 6 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addres or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 10*s*. each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute o Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

SPECIAL ARTICLE

Some principles of measurement and control

By J. F. Coales, O.B.E., M.A., M.I.E.E., F.Inst.P., Department of Engineering, University of Cambridge

Measurements can be divided into two broad classes: those which only have to be observed and recorded and those which are used to control sources of power in order to change some quantity such as position, speed, temperature or pressure. In both cases the principles are the same and there are certain limitations from which all measuring instruments suffer, e.g. they all disturb the physical system on which the measurements are being made and they all have inertia and damping to some degree. Also, no measuring instrument is completely stable and all exhibit unwanted fluctuations if the sensitivity is increased to the limit of usefulness.

In the paper these limitations are discussed together with the principles underlying the design of measuring systems to reduce their effect to a minimum. The simple theory of linear control systems is developed and it is shown that the only real difference between measuring systems and control systems lies in the magnitude of the power required at the output. Negative feedback in a closed-loop system is shown to be the equivalent of the restoring force in an open-loop system.

1. INTRODUCTION

n scientific investigation measurements are usually made in rder to discover more about some phenomenon not properly nderstood or in the verification of some hypothesis or theory. n industry, on the other hand, measurements are made in rder to control some process within sufficiently close limits o that the product is satisfactory. In the latter case the easurements made may be analysed and then used later by n operator to correct faults manually as in the case of uality control, or they may be used directly to make the ecessary corrections by automatic means. To divide easurements into these broad classes is, of course, an overmplification since in engineering design, measurements have o be made to test the design in such a way that possible eans of improvement can be devised. Broadly, however, easurements can be divided into the two classes:

(1) those which have to be observed and recorded;
(2) those which are used to control sources of power, in order to change some quantity, e.g. position, speed, temperature, flow, pressure.

Although many different physical quantities have to be bserved and measured there are certain principles underying all measuring systems of either class and certain mitations from which they all suffer. All measuring instruents disturb the physical system on which the measurement s being made and also they all have inertia or its equivalent. urther, no measuring instrument is completely stable; there ill always be some change of its characteristics with time nd in the extreme all materials exhibit Brownian motion, if he sensitivity of the system is increased to the limit of sefulness.

Fortunately most measurements can be made to sufficient ccuracy without these limitations becoming apparent, but as cientific knowledge increases greater accuracy of measureent is required. In control problems also the requirements re ever becoming more stringent so that eventually a stage ust be reached when these limitations cannot be ignored nd the problem arises of how to reduce their effect to a inimum.

The only real difference between measuring systems and ontrol systems lies in the magnitude of the power required t the output. The output of the former is an indication on a meter or a cathode-ray tube which has small inertia and requires little power to move it sufficiently fast even when a recorder is required to give a permanent record. In a control system on the other hand, inertia of the load, as it is called, may require many horsepower to move it or it may be the actual power itself which is being controlled.

2. THE BASIS OF MEASUREMENT

2.1 *Datum and coincidence.* The measurement of any quantity, in general, demands both the fixing of a datum or fiduciary point and the determination of a coincidence of the ordinate with a point on a known scale. As a rule this comparison is made visually because the eye can detect very small misalinements when the quantity to be measured is by some means or other laid alongside a known scale. Further, the accuracy, with which the datum is fixed and the coincidence of the ordinate is determined, can be increased by optical means up to the limit imposed by random fluctuations or the resolving power of the optics. With this limit the minimum scale unit is reached and the result of the observation then has the maximum possible information content (see Section 3).

2.2 *Methods of coincidence detection.* Touch can be used to determine coincidences, but the accuracy is never great and this sense is not used in any measurement of importance. Hearing, on the other hand, has been used in physical measurements by observing changes either of frequency or of amplitude. In the case of changes of amplitude the ear is most insensitive and its use is limited to null methods where the unknown quantity is balanced against a similar known and variable quantity. When in a null method the balance has been obtained, however, the value of the varied quantity must be determined and this usually depends on visual observation of a scale. Some quantities have been measured by change of frequency, coincidence having to be made with a variable frequency of known law but again, when the comparison has been made, the value of the frequency will almost certainly have to be read from a visual scale. Thus in the measurement of all continuously variable quantities the final comparison of the magnitude with a fixed scale must be carried out visually, two coincidences having to be assured.

If, however, the quantity can be measured by counting a number of events, the magnitude of which is unimportant, then any of the senses may be used, hearing, seeing or feeling, without loss of discrimination. In some cases where the difference in magnitude between successive events is of importance, the magnitude of the events (or pulses) may be observable and have to be taken into account. The difference between the two classes of measurement is important when considering the medium of transmission to be employed.

2.3 *The inertia of indicators.* In classical physics any quantity was measured as a mechanical displacement either directly or else as an electric voltage or current, later converted into the movement of a pointer on a scale. With the advent of the cathode-ray tube, however, it became possible to display and measure quantities which could be detected as electric potentials and currents without converting them into mechanical movements. The very small inertia of the electron beam in the cathode-ray tube makes it possible to make measurements very rapidly but may introduce greater uncertainty in the scale factor than usually arises with electrical measuring instruments and galvanometers.

At this point it is important to appreciate that, in order to make any measurement, power must always be transferred to the measuring instrument in one form or another. A pointer cannot be moved or a cathode-ray tube beam deflected without using some power, which must either be provided by the phenomenon itself or from some subsidiary source controlled by it. In the latter case a valve must be controlled which will itself require power to operate it or an amplifier must be provided, the input to which will again absorb some power.

2.4 *Conversions of representation of information.* There are very few measurements which are made direct, the vast majority necessitating one or more conversions from one sort of power to another. All these conversions should be considered as part of the system, which transmits the data from the phenomenon being investigated, to the observer, whether he is close-by, in the next room, 100 miles away or on a distant star. The transmission medium may well have to be different according to where the observer is and the greater the distance the more conversions from one sort of energy to another that may be required. If the observer is close-by only one conversion, say from electrical to mechanical energy, may be necessary. If, however, the information has to be transmitted to an observer 100 yards distant, electrical quantities may either be sent by cable before conversion to mechanical energy or, after conversion, mechanical signals may be transmitted by rod, whichever is the more convenient. Unfortunately, all too often in complicated systems the electrical quantities have been converted into mechanical movements close-by, which have then, by some transducer, been converted back into electrical quantities for transmission by cable or radio to the distant observer, where they have again had to be converted into mechanical power to operate an indicator or recorder. In some cases this may be the best arrangement economically, but often it has been because the method of transmission of the measured quantity from phenomenon to observer has not been considered as a whole.

We have seen that the measurement of any desired quantity is dependent on the conversion of that quantity into a mechanical movement in such a way that it follows a known law. Thus, in order to measure the temperature of an enclosure we put a thermometer into it which converts the temperature into the mechanical expansion of a liquid according to a known law. The thermometer is, in fact, a transducer converting temperature into mechanical movement. A transducer is a "mechanism" which converts one sort of energy into another according to a known law and it is axiomatic that it is impossible to obtain any informa without an exchange of energy. In this case, in order to m the measurement, the thermometer must take sufficient energy from the space to raise its own temperature to of the space and it is this energy which is "transduced" the mechanical work required for the expansion of mercury or other liquid. Thus the bulb of the thermom is a true transducer. If now, as in a mercury/steel ther meter system, we have a long steel capillary tube connec the bulb with a glass capillary set against a scale in a rem position (Fig. 1), we have the simplest form of measu and transmission system, consisting of transducer, tra mission line and indicator. These three parts will be seen be essential elements of almost all measuring systems. the case of the thermocouple system of Fig. 2 there m also be a transducer at the receiving end in the form c voltmeter. Thus in general we have a transducer at b transmitting and receiving ends corresponding to the mo lator and demodulator of a communication system.

Until the advent of the cathode-ray tube all indica were mechanical in nature and electrical quantities could c be observed after being "transduced" by galvanomet voltmeters or ammeters which imposed severe limitations the bandwidth of the frequency response. The cathode- tube still converts the electrical energy into mechan energy, but as already mentioned the inertia is very grea reduced and an enormous increase in frequency response a bandwidth is possible, but unfortunately only at the expe of greater uncertainties of scale factor and scale position th usually arise with electrical measuring instruments a galvanometers. Although the pointer is now a cathode- tube spot the actual indicator still has a fixed scale, and detector is still the eye. Thus the deflecting system of cathode-ray tube is just as much a transducer as a voltme or galvanometer and there must still be energy transfer fr the transmission line to the electron beam.

In some measuring systems it may be necessary to transdu from one sort of energy to another several times. F instance, in the temperature measuring system of Fig. 1 the transmission had to be over a long distance, it wou clearly be inconvenient to use mercury in a steel tube. T mechanical movement would then have to be converted in an electric voltage which might be transmitted and th reconverted into a mechanical movement as in Fig. 2. this case there will be three transducers instead of o These conversions do not necessarily impair the accura

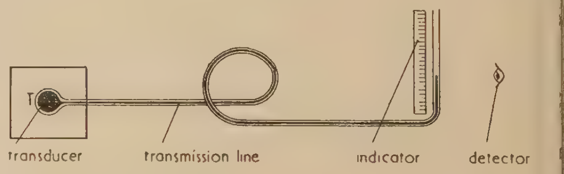


Fig. 1. A simple measuring system

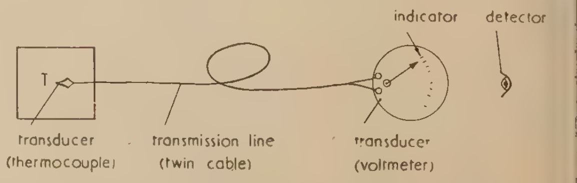


Fig. 2. Electrical measurement of temperature

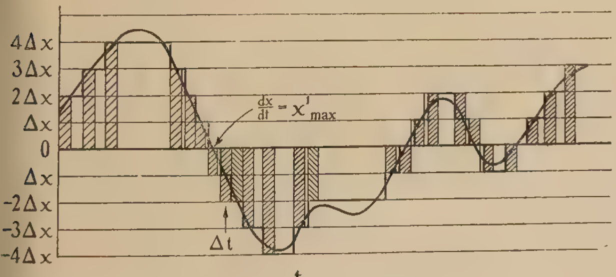
f the measurement, but they may do so by the introduction f noise and in general they reduce the simplicity of the ystem and should be avoided.

The above considerations apply equally to the measure-ient of discontinuous quantities which depend on counting perations. In such cases the counter may be a special type f transducer converting a number of pulses of energy E into continuous quantity W in such a way that $W = f(n)E$ here $f(n)$ is known. It may then be situated either at the ansmitting or receiving end of the transmission line accord-ig to which provides the simplest and most reliable system.

3. INFORMATION CONTENT AND THE DESIGN OF A MEASURING SYSTEM

No matter what the quantity to be measured, if it is varying time there will always be some limit to the time in which e measurement is made. There are, of course, some easurements such as the comparison of densities on a otographic plate for which time is of no importance and replaced by a linear dimension.

If the quantity is varying very slowly then the time δt quired to make an observation can be great and the equency bandwidth δf which must be accepted can be nall whereas, if the quantity is subject to rapid variations, will be small and δf correspondingly great. We have also en that any measurement is dependent on transfer of power the transducer. In designing a measuring system we must st decide what bandwidth must be used. This will depend the accuracy with which we wish to make the measurement d the rate of change of the phenomenon, which we will sume to be known. Because of random fluctuations in the ansducer there is always an eventual limit to the smallest ange that can be observed. This limit has been called by ackay the proper scale-unit, δx, and has been defined by m as that interval for which, when an observation is x ch units, the probability is just $\frac{1}{2}$ that the true value of e quantity lies between $x - \frac{1}{2}\delta x$ and $x + \frac{1}{2}\delta x$. Mackay s also shown that the average energy transfer necessary to serve a change of one proper scale-unit cannot be less than e photon, or hf, when the number of photons is small, $\frac{1}{2}kT$ (T, absolute temperature; k, Boltzmann's constant) those cases where an averaging process is involved, as in ost measurements. If the quantity $x(t)$ is to be measured the highest possible accuracy and we know that the aximum rate of change of the quantity under the conditions the experiment is $x'(t)_{max}$ we also know that the limiting ale-unit is δx, corresponding to an energy transfer $\frac{1}{2}kT$ d we can therefore quantise $x(t)$, as shown by the stepped e in Fig. 3, without loss of discrimination. Each horizontal portion of the stepped line represents the average value of $x(t)$ taken over the interval of time corresponding to the distance between the vertical lines. A change in x can only be observed when the mean value has altered by a minimum amount δx* and so the vertical lines indicate the times at which the probability of observing a change of δx exceeds $\frac{1}{2}$. We thus see that if the maximum rate of change of $x(t)$ is $x'(t)_{max}$ then the probable shortest interval between successive observations of change is $\delta t = \delta x / x'(t)_{max}$. Thus under the worst conditions we must observe the change δx in time δt and in order to do this with probability $\frac{1}{2}$, which is all we require since this is the limiting accuracy of $\delta \dot{x}$ and δt, we shall need a bandwidth δf such that $\delta f . \delta t \simeq 1$. Thus the minimum bandwidth that must be used is $\delta f = 1/\delta t$ and this corresponds to the δf in Gabor's information diagram (see bibliography). This represents the limiting accuracy of one measurement under the ideal conditions of adequate bandwidth, the introduction of *no* external noise and a perfect transfer of the average energy $\frac{1}{2}kT$ per metron.† This measurement is made in a time δt and if we are continuously recording the quantity $x(t)$, provided the bandwidth is δf, a measurement will be made in each successive interval δt. In this case, increasing the bandwidth δf will add no additional information since we have postulated that $x'(t)_{max}$, or in other words, the fineness of structure, is known. If $x'(t)_{max}$ is not known then it may be desirable to continue increasing δf until there is no apparent increase in the observed value of $x'(t)_{max}$. The quantity δx represents the proper scale-unit for x under ideal conditions and each measurement x will contain $x/\delta x$ *metrons* or $\log_2 (x/\delta x)$ *bits* of information. If, however, we have a system with overall feedback as we shall see in Section 5 the amount of wanted information passed to the transducer and amplifier never exceeds one *metron* and the useful energy (as opposed to noise) transferred, on the average, never exceeds $\frac{1}{2}kT$.



[Reproduced from *Proceedings of the Institution of Electrical Engineers*]

Fig. 3. Quantization of a continuously varying function of time

Unfortunately, however, no measurement can be made under completely quiet conditions and there will, in general, always be unwanted disturbances such as may come from electric machinery in the vicinity of magnetic measurements. In Fig. 4 we represent these external disturbances by a function $N(t)$ and the tranducer will receive a signal $x(t) + N(t)$. For any period δt there will clearly be a corresponding energy, the average value of which we can write as $\frac{1}{2}kT_1$ and in each interval of time the transducer will receive, on the average, energy

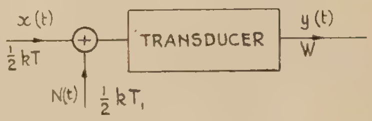


Fig. 4. Transducer with input signal and noise

$$\overline{W(t)} = \tfrac{1}{2}kT + \tfrac{1}{2}kT_1 = \tfrac{1}{2}k(T + T_1) \qquad (1)$$

Thus the addition of extraneous noise is equivalent to raising the temperature of the system by T_1.

4. LINEAR ANALYSIS

4.1 *Step and impulse response of simple transducer.* We have seen that when we make a measurement, the rapidity with which the quantity to be measured is changing and the accuracy to which we wish to make the measurement will decide the time in which it must be made and hence the bandwidth required for the measuring instruments.

---

* Δx is used on Fig. 3.

† If a measurement results in an observation corresponding to a value M proper scale-units above a fixed datum, the observation is said to contain M metrons of information.

We have also seen that whenever a measurement is made, energy has to pass to the transducer and this takes time. It is usual to consider what happens to the output $y(t)$ of the transducer (Fig. 5) when a small change occurs at the input so let us consider the mercury glass thermometer system.

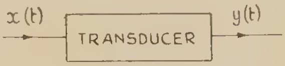


Fig. 5

If the thermometer is suddenly transferred from an enclosure at temperature T_0 to one at temperature T_i, heat will flow through the glass into the mercury at a rate $K(T_i - T_0)$ where K is the heat transfer constant dependent on the size, shape and material of the bulb. The temperature T_0 of the mercury will rise at a rate dT_0/dt given by this heat flow divided by its mass M and specific heat S so that

$$\frac{dT_0}{dt} = \frac{K(T_i - T_0)}{MS} \quad \text{or} \quad \left(\frac{MS}{K}\right)\frac{dT_0}{dt} + T_0 = T_i \qquad (2)$$

It is immediately evident that as the temperature T_0 of the thermometer approaches that of the enclosure, the rate of change dT_0/dt gets smaller and T_0 approaches T_i asymptotically as in Fig. 6.

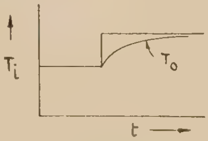


Fig. 6. Transient response of a simple measuring instrument

If we put $MS/K = \tau$, the solution of equation (2) is

$$T_0 = T_i[1 - \delta e^{(t_0 - t)/T}] \qquad (3)$$

where $\delta = T_i - T_0$ is the value of the step function applied at time t_0; so that for any sudden change in T_i the output T_0 rises exponentially to the new value, the time taken to approach T_i, within a certain proportion, increasing with τ, which is known as the time-constant.

This is the exact equivalent of the resistance capacity combination of Fig. 7, for which

$$CR\frac{dE_0}{dt} + E_0 = E_1(t) \qquad (4)$$

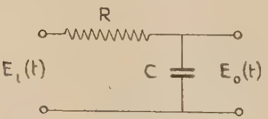


Fig. 7

The general solution of this equation can be shown to be

$$E_0(t) = A_e^{-t/T} + \frac{1}{T}\int_0^t E_i(\tau)\, e^{(t-\tau)/T} d\tau; \quad T = CR \qquad (5)$$

The term $A\,e^{-t/T}$ is the general solution of the homogen equation

$$T\frac{dE_0}{dt} + E_0 = 0$$

and the second term is a particular solution of the homogeneous equation (4).

In order to determine the output $E_0(t)$ not only must input $E_i(t)$ be known but also the adjustable constants w are determined by the initial conditions. Conversely making a measurement, $E_i(t)$ can in general only be d mined from $E_0(t)$ if the time-constant T and the initial ditions at time $t = 0$ are known.

If at $t = 0$, $E_0(t) = 0$, then $A = 0$ and

$$E_0(t) = \frac{1}{T}\int_0^t E_i(t - \tau) e^{-\tau/T} d\tau$$

by changing the variable of integration.

It will be seen that this relation expresses the output network or transducer as a weighted mean of all past va of the input (i.e. to time $t = 0$; if greater generality is nee the lower bound can be made $t = -\infty$).

Considering first a sudden change in $E_i(t)$ from zero all times up to $t = 0$ to a constant value E_i immediately $t = 0$ we have from equation (7)

$$E_0(t) = E_i(1 - e^{-t/T})$$

giving the transient response of the system in exactly same form as equation (3). If, however, we consider behaviour of the system for a very short impulse of du δt and magnitude E_i occurring immediately after time t we have that for $\tau = t - \delta t$ to $\tau = t$, $E_i(t) = E_i$ and a other times $E_i(t) = 0$ so that

$$E_0(t) = \frac{1}{T}\int_0^{t-\delta t} E_i(t-\tau)\, e^{-\tau/T} d\tau + \frac{1}{T}\int_{t-\delta t}^{t} E_i(t-\tau)\, e^{-\tau/T} d$$

$$= E_i[e^{-(t-\delta t)/T} - e^{-t/T}]$$

$$= E_i\delta t\, e^{-t/T}, \text{ provided } \delta t \text{ is very small}$$

We now see that at $t = 0$, the instant of the imp $E_0(t) = E_i\delta t$ and the response thereafter has the shap $e^{-t/T}$ which is therefore the weighting function or imp response of the component, the magnitude being dire proportional to $E_i\delta t$. We now define unit impulse as that

which $\int_\tau^{\tau+\delta t} E_i(t)dt = 1$ provided δt very small.

Then reverting to our previous considerations concern quantising the input quantity we can consider it as made of a large number of impulse functions of duration δt magnitude $x_t\delta t$ where x_t is the mean value over the pe δt around time t. We see therefore that no matter what component, transducer, transmission line, amplifier indicator, if it has a known response $h(t)$ to unit impulse for any input $E_i(t)$ which is some known function of ti the output can also be expressed as a function of ti

$$y(t) = \int_0^t x(t - \tau)h(\tau)d\tau$$

provided only that the component is linear, i.e. that remains unchanged and the law of superposition applies the range of input values concerned.

Clearly the impulse response $h(t)$ will be different for ferent components and is a characteristic of the particular mponent. As we shall see later it is directly related to the quency response.

So far we have only considered the response of a very nple transducer, but we saw that any system will almost tainly include an amplifier which will be followed by an licator or recorder which will have inertia. More precisely, : indicator must have a motor which will produce a force torque proportional to the output of the amplifier, which ll operate on the mass or inertia of the pointer or pen. : will assume that the pointer or pen is working against a ear spring to provide a restoring force, so that in the steady te, when any transient phenomena have died out, the lication $y = KT_i$. The complete system will therefore be shown in Fig. 8.

If, when $t = 0$, $x = x_0$ and $y = y_0 = x_0/L$, this again gives a relation of the form

$$y(t) = \frac{x_0}{L} + \int_0^t x(t-\tau)h(\tau)d\tau \qquad (16)$$

where

$$h(t) = \frac{\omega_n}{2(\alpha^2-1)^{\frac{1}{2}}} \exp(-\alpha\omega_n t)\left\{\exp\left[(\alpha^2-1)^{\frac{1}{2}}\omega_n t\right] - \exp\left[-(\alpha^2-1)^{\frac{1}{2}}\omega_n t\right]\right\}$$

It is seen that the form of this depends on whether α is less than, equal to, or more than one. If $\alpha \leqslant 1$, $h(t)$ simplifies as follows:

$$\alpha < 1,\ h(t) = \frac{\omega_n}{(1-\alpha^2)^{\frac{1}{2}}} \exp(-\alpha\omega_n t) \sin(1-\alpha^2)^{\frac{1}{2}}\omega_n t \qquad (17)$$

$$\alpha = 1,\ h(t) = \omega_n^2 t \exp(-\alpha\omega_n t) \qquad (18)$$

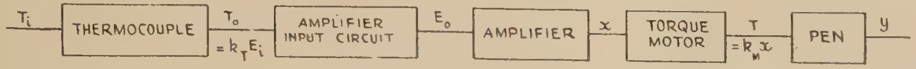


Fig. 8. Block diagram of temperature recorder

If the pen has moment of inertia J and frictional resistance portional to its angular velocity we shall have the well-own relationship

$$J\frac{d^2y}{dt^2} + F\frac{dy}{dt} + Ly = T \qquad (11)$$

ere F is the frictional force for unit velocity and L the ing force for unit displacement.

We can treat this differential equation in exactly the same y as the first order equation but it is convenient to divide ough by J and put $L/J = \omega_n^2$ and $F/2(JL)^{\frac{1}{2}} = \alpha$ giving

$$\frac{d^2y}{dt^2} + 2\alpha\omega_n\frac{dy}{dt} + \omega_n^2 y = \frac{T}{J} = \frac{k_M x}{J} \qquad (12)$$

The general solution of this equation is as before the sum the general solution of

$$\frac{d^2y}{dt^2} + 2\alpha\omega_n\frac{dy}{dt} + \omega_n^2 y = 0 \qquad (13)$$

is a particular solution of equation (12).

The first is easily shown to be of the form

$$y(t) = A_1 e^{r_1 t} + B_1 e^{r_2 t} \qquad (14)$$

and r_2 being the roots of the equation

$$r^2 + 2\alpha\omega_n r + \omega_n^2 = 0$$

that

$$r_1 \text{ and } r_2 = \alpha\omega_n \pm j\omega_n(1-\alpha^2)^{\frac{1}{2}} \qquad (15)$$

ese roots, r_1 and r_2, may be of three possible forms depend-; on the magnitude of the damping ratio α. When $\alpha < 1{\cdot}0$, : roots are conjugate complex with negative real parts and : system is underdamped; when $\alpha = 1{\cdot}0$, the roots are gative, real and equal and the system is critically damped d when $\alpha > 1{\cdot}0$, the roots are negative, real and unequal d the system is overdamped. Each form of the roots es a different form of the time solution.

The particular solution will depend on the form of the cing function on the right-hand side of equation (12), ether it is an impulse function, a step function, a sinusoid, ., and on the initial conditions.

The forms of the impulse response for the three cases are given in Fig. 9. It is immediately evident that when $\alpha < 1$ the response is oscillatory though damped and if α could be zero a steady oscillation would be maintained at frequency ω_n which is known as the natural frequency of the system. When $\alpha = 1$ the system is critically damped and does not oscillate, for this reason α is known as the damping ratio. When $\alpha > 1$ the system is underdamped and takes longer to reach equilibrium. The equivalent transient responses for a step-input, where the input $x(t)$ changes by one unit at $t = 0$ and is maintained at x_1, therefore, are shown in Fig. 10.

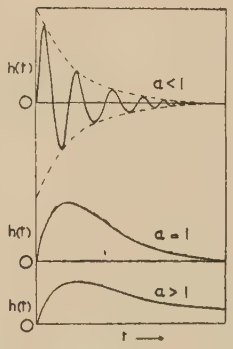


Fig. 9. Impulse response of an instrument with inertia and damping

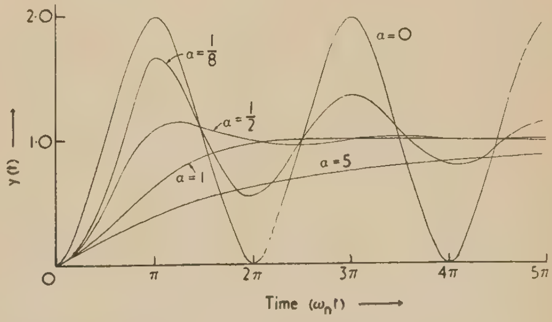


Fig. 10. Step response of instrument with inertia and damping

4.2 *Higher order systems: the use of Fourier and Laplace transforms.* In a similar way the impulse response can be found for any system, provided it is linear, if the characteristic differential equation can be written down. Thus if we consider the thermocouple system of Fig. 8 as a whole we shall write down the relationships in sequence as follows:

For the transfer of heat to the thermocouple

$$\tau_T\, dT_0/dt + T_0 = T_i \qquad (19)$$

For the input circuit of the amplifier which must include resistance and capacity as in Fig. 7,

$$\tau_A\, dE_0/dt + E_0 = E_i = k_T T_0 \qquad (20)$$

For the output from the amplifier and the torque-motor

$$x = k_A E_0$$
$$T = k_M x = k_M k_A E_0 \qquad (21)$$

and for the load or indicator

$$\frac{d^2y}{dt^2} + 2\alpha\omega_n \frac{dy}{dt} + \omega_n^2 y + \frac{T}{J} = k_M k_A \frac{E_0}{J} \qquad (22)$$

It is now convenient to go to operational methods of solving the equations in order to avoid having to solve complicated integral equations. Space does not permit of explaining the Laplace transform method so suffice it to say that for all the characteristic equations that arise the solutions can be expressed in terms of e^{st} where s is some number real or complex, provided the input or forcing function appearing on the right-hand side in the above expression is simple, i.e. an impulse function, a step function or a sinusoid containing only one frequency, $\sin \omega t$, $\cos \omega t$ or $e^{j\omega t}$. The system being linear, the law of superposition applies so that if we know the solution for a frequency ω_1 and a frequency ω_2, we can obtain the solution for any combination of ω_1 and ω_2 merely by adding the appropriate solutions for the two cases, maintaining the correct phase relationship.

It is well known that any function of time can be expressed as a combination of sinusoids by means of a Fourier integral, so that, if the output can be calculated for each of the Fourier components of the input, simple summation will give the output as a function of time for the known arbitrary input. It can also be shown that if the input $x(t)$ to any linear component, filter or control system is a pure sinusoid $x_0 e^{j\omega t}$, which theoretically must have started at $t = -\infty$, then the output must also be a sinusoid of the same frequency, differing from the input only in magnitude and phase. In practice, of course, the sine wave must be switched on at some time, say $t = 0$, and the input will contain some transient in addition to the sinusoid. The transient will, of course, produce an output also transient, as follows from the discussion of impulse response, so that it will die away quite rapidly if the system is stable, after which time the system is said to have reached the steady state when only the fundamental frequency will be present in the output. It should be noted at this point that there is no difficulty in expressing the combination of sinusoid and switching transients as a Fourier integral of pure sinusoids all starting at $t = -\infty$ which will produce an output in which all frequencies appear with the appropriate amplitudes and phases so that at a certain time the steady state is reached, when they all cancel each other out except the fundamental.

Because a linear system with a pure sinusoid as input always has a pure sinusoid of the same frequency as output, differing from the input only in magnitude and phase, linear systems are said to be distortionless. It is a feature of linearities that they introduce distortion, i.e. harmonics

Returning now to the relationships between input and put of any component and writing the input $x(t) = x_0 e$ assume that the output is $y(t) = y_0 e^{j(\omega t + \phi)}$ where represents the change in amplitude and ϕ the change in

$$\text{Then} \qquad \frac{dy}{dt} = j\omega\, y_0 e^{j(\omega t+\phi)} = j\omega y(t)$$

so that replacing T_i by x and T_0 by y equation (19) bec

$$(j\omega\tau_T + 1)\, y = x$$

This can be solved by writing

$$(j\omega\tau_T + 1)\, y_0 e^{j(\omega t+\phi)} = x_0 e^{j\omega t}$$

or

$$(j\omega\tau_T + 1)\, y_0(\cos\phi + j\sin\phi) = x_0$$

and equating real and imaginary parts

$$y_0(\cos\phi - \omega\tau_T \sin\phi) = x_0$$
$$j y_0(\omega\tau_T \cos\phi + \sin\phi) = 0$$

$$\text{Whence} \qquad \frac{y_0}{x_0} = \frac{(1 + \omega^2\tau_T^2)^{\frac{1}{2}}}{1 - \omega^2\tau_T^2} \text{ and } \tan\phi = -\,\omega\tau_T$$

As might be expected, the amplitude ratio (usually gain or attenuation) and phase both change with fre or more correctly with the non-dimensional variab The shape of these functions is the same for all first- systems, the parameters, on which τ depends, only cha the frequency scale in such a way that the greater the constant τ the more rapidly the attenuation increases frequency or the smaller the bandwidth, as might be expe

Returning now to the measuring system of Fig. 8 an equations (19) to (22) we can re-write these in their La transform form using the symbol $\bar{y}$ to denote the La transform of y and similarly for the other quantities

$$(s\tau_T + 1)\bar{T}_0 = \bar{T}_i$$
$$(s\tau_A + 1)\bar{E}_0 = \bar{E}_i = k_T\bar{T}_0 = k_T\bar{T}_i/(s\tau_T + 1)$$
$$(s^2 + 2\alpha\omega_n s + \omega_n^2)\bar{y} = k_M k_A \bar{E}_0$$
$$= k_M k_A k_T T_i/(s\tau_T + 1)(s\tau_A +$$

so that

$$\bar{y} = \frac{k_M k_A k_T \bar{T}_i}{(s\tau_T + 1)(s\tau_A + 1)(s^2 + 2\alpha\omega_n s + \omega_n^2)}$$

If the Laplace transform of T_i is known, $\bar{y}$ can be calcu and $y(t)$ is then the inverse Laplace transform.

If we are interested in frequency response, we only to replace the variable s by $j\omega$ and calculate the gain phase of

$$H(j\omega) = \frac{k_M k_A k_T}{(s\tau_T + 1)(s\tau_A + 1)(s^2 + 2a\omega_n s + \omega_n^2)}$$

which is known as the transfer function of the system different values of ω. This transfer function in terms of corresponds in the frequency domain to the impulse resp $h(t)$ in the time domain used in equation (16). It is w noting that since the overall transfer function is the pro of the transfer functions of the components in series gains at any given frequency have to be multiplied tog and the phases have to be added. It is therefore usu plot the logarithm of the gain against frequency (or quency) since then both log gain and phase plots can be ded directly.

f the input $x(t)$ is a random process which is observed a long time $2T$ and is assumed to vanish outside this erval, then $x(t)$ can be developed into a Fourier integral.

$$x(t) = \int_{-\infty}^{\infty} X(\omega)e^{j\omega t}d\omega \tag{28}$$

ere $X(\omega)$ is the amplitude of the frequency ω. By inversion

$$X(\omega) = \frac{1}{2\pi}\int_{-T}^{T} x(t)e^{-j\omega t}dt \tag{29}$$

We can now calculate the mean square value $\overline{x^2}$ of $x(t)$ in ms of $X(\omega)$ as

$$\overline{x^2} = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} x^2(t)dt \tag{30}$$

$$= \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} dt \int_{-\infty}^{\infty} d\omega d\omega' X(\omega)X(\omega')e^{j(\omega+\omega')t}$$

$$= \lim_{T\to\infty} \frac{4\pi}{2T}\int_{-\infty}^{\infty} |X(\omega)|^2 d\omega \tag{31}$$

d putting $\Phi_x(\omega) = \lim_{T\to\infty} \frac{2\pi}{T}|X(\omega)|^2$

is yields $\overline{x^2} = \int_0^{\infty} \Phi_x(\omega)d\omega$ (32)

ow referring to equation (27) it is easily seen that if $Y(\omega)$ the amplitude of the output at frequency ω,

$$y(t) = \int_{-\infty}^{\infty} Y(\omega)\, e^{j\omega t}\, d\omega \quad \text{and} \quad Y(j\omega) = H(j\omega)X(j\omega) \tag{33}$$

therefore follows that

$$= \int_0^{\infty} \Phi_y(\omega)d\omega$$

$$= \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} dt \int_{-\infty}^{\infty} d\omega d\omega' H(j\omega)X(j\omega)H(j\omega')X(j\omega')e^{j(\omega+\omega')t}$$

$$= \int_0^{\infty} \Phi_x(\omega)\Psi_h(\omega)d\omega \tag{34}$$

ere $\Psi_h(\omega) = H(j\omega)H^*(j\omega) = |H(j\omega)|^2$ which is the quency response of the system.

We can now link up this analysis in terms of frequency sponse with the considerations of Section 3. In Section 3 saw how to obtain a measure of the total power, $\frac{1}{2}kT$, d the bandwidth δf of the fluctuations of the observations out the true value. If the probability distribution of the put is known then the power spectrum $\Phi_x(\omega)$ can be tained as the Fourier transform of the autocorrelation nction. Alternatively the fluctuations must be assumed to of some known type of distribution, Gaussian, Poisson, yleigh or binomial, when by use of the values for $\frac{1}{2}kT$ and δf, $\Phi_x(\omega)$ can again be calculated. It should be noted that the square of the deviation about the mean, $\overline{x^2}$, is the total power in the fluctuations and must therefore be equal to $\frac{1}{2}kT$.

It is evident that in designing a system either all the information available at the input is required at the output, in which case the amount of noise entering the system must be reduced to a minimum and there must be no reduction in bandwidth due to the various components which are used or alternatively the accuracy and hence the amount of information, in terms of scale-unit and bandwidth, required at the output will be known and the components can be designed accordingly in the light of analysis of the type given above.

Further in the first case, in which the best possible accuracy is required, the sources of noise in the system are certain to impair the accuracy but if the power spectra (not necessarily the same) at one point in the system are known, they can always be calculated at any other point in the system, provided it is linear, and the principles of information theory can be invoked to calculate the required frequency response of a filter to give the best discrimination between signal and noise. Under these circumstances it is, of course, axiomatic that the very low-level signals at the input must always be amplified as early in the system as possible with the introduction of as little noise as possible so that when further noise of equivalent temperature T_n and noise power $\frac{1}{2}kT_n$ gets added, it is to an amplified signal power $\frac{1}{2}KkT$ where K is the factor by which the power has been amplified and so the effect of the noise on the signal is very much reduced, i.e. by the factor K.

5. NEGATIVE FEEDBACK

If in the measuring system of Fig. 8 we feed back the output $y(t)$ to the input of the torque-motor and subtract it from $x(t)$ we can represent the system in block form as in Fig. 11.

$$\left.\begin{aligned} \frac{d^2y}{dt^2} + 2\alpha\omega_n\frac{dy}{dt} + \omega_n^2 y &= \frac{k_m}{J} \\ e(t) &= x(t) - y(t) \end{aligned}\right\} \tag{35}$$

or rearranging

$$\frac{d^2y}{dt^2} + 2\alpha\omega_n\frac{dy}{dt} + \left(\omega_n^2 + \frac{k_m}{J}\right)y = \frac{k_m x}{J} \tag{36}$$

and rearranging again:

$$\frac{d^2e}{dt^2} + 2\alpha\omega_n\frac{de}{dt} + \left(\omega_n^2 + \frac{k_m}{J}\right)e = \frac{d^2x}{dt^2} + 2\alpha\omega_n\frac{dx}{dt} + \omega_n^2 x \tag{37}$$

Comparing equations (36) and (12) we see immediately that the effect of the negative feedback is to increase the "springterm" and so effectively to increase the natural frequency of the system. From this it follows that the physical spring restoring force, which had to be provided, can be replaced by negative feedback, provided the open

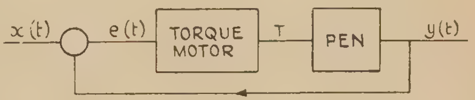


Fig. 11. Block diagram of recorder with negative feedback

loop gain, as it is called, k_m, is large enough to give a sufficiently high natural frequency. Having made $L/J = 0$, we now have $\omega_n^2 = k_m/J$. When negative feedback is used instead of a spring restoring force, the transfer function of the pen or the motor and load is of the form

$$Y(s) = \frac{1}{Js[1 + (F/J)s]} \tag{38}$$

and it is seen that then $\omega_n^2 = k_m/J$ and $\alpha = F/2(k_mJ)^{\frac{1}{2}}$. The solution of the equation (36), of course, follows exactly the same course as that of equation (12) and the response will depend on the damping coefficient α in exactly the same way as before. It will, however, be noticed that as k_m is increased, which may be necessary to increase bandwidth or frequency response of the system, as discussed above, the damping factor α is reduced and so the system becomes more and more oscillatory which may well result in a quite unsatisfactory transient response.

It will be clear from equation (35) that if the system is of high performance, which usually demands high forward loop gain $y(t) \simeq x(t)$ and $e(t)$ will always be small whatever the value of $x(t)$. If, therefore, we can make the loop gain sufficiently large we can reduce the range of the input to the torque motor, or the amplifier if we feed the output back to its input, to any desired value. Further, if we apply overall feedback from the output to the input of the first transducer we can, by making the loop gain large enough, restrict the variations of the input quantity to the first transducer, to plus or minus one proper scale unit, thus reducing the likelihood of saturation of any of the components.

When feedback is used, it is easily seen from equations (35) to (37), (27) to (29) (and can be proved rigorously by Laplace transform methods) that, if as in Fig. 12 the transfer function of the open loop system without feedback is $Y(s)$, then the transfer function of the system as a whole is $Y(s)/[1 + Y(s)]$

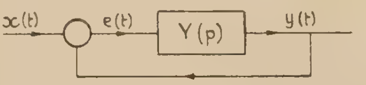


Fig. 12. Block diagram of closed loop control system

or

$$\bar{y} = \frac{Y(s)}{1 + Y(s)}\bar{x} \tag{39}$$

where $\bar{x}$ and $\bar{y}$ are the Laplace transforms of $x(t)$ and $y(t)$ respectively. If $Y(s)$ is an amplifier of gain G independe frequency then, if $G \gg 1$,

$$\left.\begin{aligned} \bar{y} &= \frac{G}{1+G}\bar{x} \simeq \bar{x} \\ \text{and} \qquad \bar{e} &= \frac{\bar{x}}{1+G} \rightarrow 0 \text{ as } G \rightarrow \infty \end{aligned}\right\}$$

Of course in practice it is not possible to have amp or any other components, for which the gain is independent of frequency, and so it is inevitable that tra functions of the type given in equation (38) arise. such a transfer function is inserted in equation (39) it w found that it is possible for some of the roots of the equ for the output $y(t)$ to have positive real parts, i.e. the sol will be of the form

$$y(t) = Ae^{-(\alpha_1+j\omega_1)t} + Be^{-(\alpha_1-j\omega_1)t} + \\ + C\,e^{-(\alpha_2+j\omega_2)t} + D\,e^{-(\alpha_2-j\omega_2)t}$$

If this is the case, after any disturbance of the input $x($ output $y(t)$ will clearly go on oscillating with frequenc and ever increasing amplitude, in other words the syste unstable. This instability can usually be overcome reducing the gain of the system but this will probabl unsatisfactory because it will reduce the frequency resp and so it is usual to insert compensating networks o required transfer function $Y_A(s)$ which will modify characteristic equation (31) in such a way as to make it st

The design of such networks is too large a subjec discuss here. It is in fact not only the essence of co engineering in general but also of electronic amplifiers communications systems.

BIBLIOGRAPHY

Mackay, D. M. *Quantal Aspects of Scientific Informa Phil. Mag.*, **41**, p. 289 (1950).
Gabor, D. "Communication Theory and Physics," *Mag.*, **41**, p. 1161 (1950).
Gabor, D. "Theory of Communication," *J. Instn E Engrs*, **93**, p. 429 (1946).
Shannon, C. E. "A Mathematical Theory of Commun tion," *Bell Syst. Tech. J.*, **27**, pp. 379 and 623 (1948).
James, H. M., Nichols, N. B., Phillips, R. S. *Theor Servomechanisms* (New York: McGraw-Hill Book Co. 1947).
West, J. C. *Textbook of Servomechanisms* (London: En Universities Press Ltd., 1953).

A new vacuum plate-camera of large capacity

By L. N. D. LUCAS, M.Sc., Ph.D., F.Inst.P., and P. B. SEWELL, B.Sc., Physics Department, University of Western Australia, Nedlands, Western Australia

[*Paper received* 8 *August*, 1956]

A multiple-plate vacuum camera for use in vertical-column type electron optical apparatus is described. The camera incorporates a new method of plate storage and selection which is very reliable in operation and makes large capacity and good pumping characteristics compatible with small volume. Design details are given for a camera of 4 litres free volume with a capacity of up to twenty-four 3¼ × 4¼ in. photographic plates.

many electron diffraction investigations it is necessary to ke a series of pattern photographs without admitting air the vacuum system. For special problems this can be ne with the aid of a roll-film camera which has the advan- ge of mechanical simplicity. For general use, however, rticularly where precision is important, the multiple-plate mera is undoubtedly superior provided the mechanical fficulties involved can be overcome without undue com- exity. The camera to be described is of the latter type and believed to be a considerable improvement on previous struments.

CAMERA MECHANISM

The principle of the camera is illustrated in Fig. 1. The × 4¼ in. photographic plates *A* are stored in a magazine uated to one side of the observation chamber of the paratus, being held in the threads of four large square-read screws *B*. Rotation of the large knob *C* causes all ur screws to rotate in unison and either raise (to load) or wer (to discharge) the plates. During assembly the screws e carefully adjusted to be "in phase" so that when, during scharge, a plate reaches the bottom ends of the threads it ops out squarely on to two flat rails *D* (½ in. wide) running derneath the magazine. The plate is then pushed along e rails by a bar E_1 running transverse to the rails and tached at each end to nylon threads *F*, passing around a ir of wheels G_1G_2 on each side of the camera mechanism. order to prevent slippage, the two ends of each thread e looped separately around and attached to the larger wheel each pair. These two larger wheels are fixed to a common le which is coupled to a drive shaft.

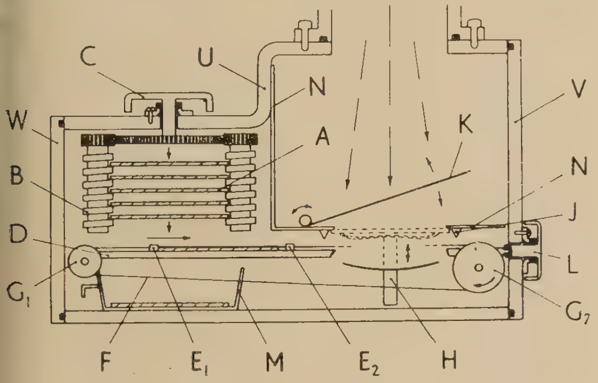


Fig. 1. Schematic diagram of camera mechanism and vacuum chamber

When the plate reaches the correct position for exposure the elevating platform *H*, which is made of thin phosphor bronze sheet and slightly concave towards the plate, is caused to rise between the rails, lift the plate into position and retain it there under pressure supplied by the elasticity of the platform. Conical pins *J* take care of any possible off-centring of the plate prior to elevation by manœuvring the plate laterally into its precise location as it rises. Exposure of the plate may be effected by swinging aside for the required time the aluminium shutter *K*, which carries the fluorescent screen on its upper surface. After exposure the above operations are reversed. The platform *H* lowers the plate on to the rails and the bar E_2, which is attached to the same threads as E_1, pushes the plate back to its original position directly beneath the magazine. Knob *L*, which is geared to both of the rails, is then rotated. This turns each of the flat rails downwards through 90° about a longitudinal axis running through its outside edge and allows the plate to fall between the rails into the metal tray *M* for storage until the vacuum chamber is opened. The rails are then restored to their original position and the cycle of operations may be repeated until the magazine is emptied.

The whole mechanism, with the exception of the shutter *K*, the light-screens *N* and the drawer *M*, is constructed as a unit between $\frac{1}{16}$ in. thick sheet brass sides braced by brass rods and other parts of the structure (see Fig. 2). Thus the mechanism may be very quickly slid in or out of the vacuum chamber on skids *O*, once the operating knobs have been withdrawn slightly to decouple them from their respective shafts. The skids run on the machined surfaces of ledges cast into the floor of the vacuum chamber.

Most of the detail of the mechanism may be followed from Fig. 2. The linkage between the two rails, consisting of a pair of gears, a bar and a cam, may be seen at the front end of the unit. This construction was favoured because of its positive action and compactness. On the other side of the bar on which this linkage is mounted may be seen a bracket *P*. This is a part of an adjustable device associated with the axle between the two large wheels G_2. Its purpose is to stop the pusher bars E_1E_2 in their two extreme positions.

The elevating platform *H* is set on the top of a piston which moves in a tube *Q* which may be seen in the photograph. A peg in the side of the piston protrudes through a vertical slot in the wall of the tube and engages in a groove in the far side of the eccentric *R*. Thus when the shaft of the eccentric is rotated the vertical motion of *H* is effected.

Considerable care was taken in the design of the brass screws *B* of the magazine section so as to avoid the possibility of the plates binding due to oversize or slipping out of the threads due to undersize. A large number of plates was therefore measured in order to find the limits of variation in plate size before deciding upon the dimensions of the screws and their spacing. The screws are located along the long edges of the plates, thereby preventing the latter from riding out of the screw threads laterally. Motion in a perpendicular direction is prevented by aluminium guide plates *S*.

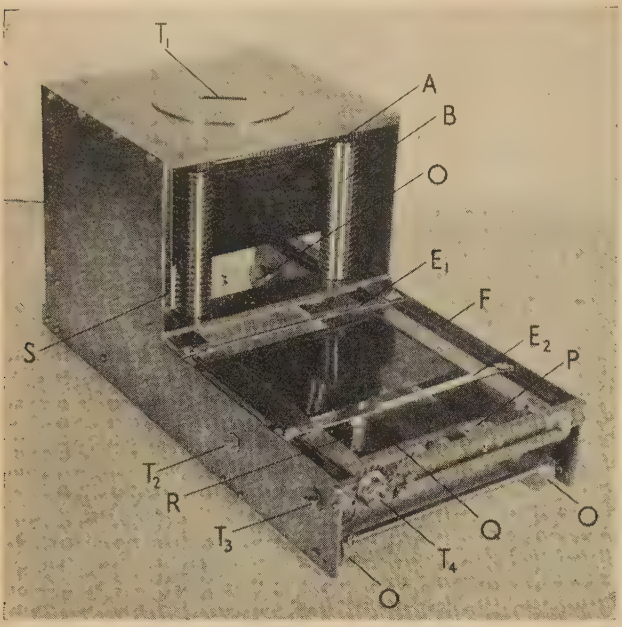


Fig. 2. Camera mechanism removed from vacuum chamber. Sixteen plates only have been loaded and racked to the top of the magazine in order to render the loading aperture and other details visible

T_1, T_2, T_3, T_4 are respectively the coupling points for the shafts operating the magazine screws, the plate elevating table, plate pusher bars and the rails.

VACUUM CHAMBER

The vacuum chamber is cast in $\frac{1}{2}$ in. thick silicon–aluminium in three pieces consisting of the main body *U* (Fig. 1), an end plate *V*, and a door *W*. Silicon–aluminium was chosen for its lack of porosity and consequent good vacuum properties.

Both the end plate and the door are sealed to the main body by spliced round-section rubber cord set in rectangular grooves. The former is attached semi-permanently by means of screws tapped into the edge of the chamber while the latter, since it needs to be opened frequently, is fastened by the quick-release device of pivoted screws and lugs as may be seen in Fig. 3. The seals for the several control shafts each incorporate two small O-rings.

As is indicated in the simplified diagram, Fig. 1, the vacuum chamber is divided into two sections by the L-shaped partition *N* which is made of brass sheet screwed to the chamber walls. Above and to the right of the partition is the diffraction chamber while the remainder is the camera section proper, the net volume of which, when loaded, is 4 litres. This is somewhat greater than it need be in most other types of apparatus due to provision being made for two alternative positions of the photographic plate during exposure. In the normal position, used for all electron diffraction work by the reflexion method, the direct beam strikes the plate app
mately one centimetre from the long edge, to the right c
observer. This position of the plate may also be use
transmission type work but if desired one may arrang
the plate to locate further to the right so that the main
strikes it in the centre, thereby registering the full patter

LOADING THE MAGAZINE

In order to load the magazine it is not necessary to re
the mechanism from the vacuum chamber. The colle
tray *M* is taken out and the plates fed to the magazine sc
one at a time on the tips of the fingers of the left hand.
each plate is pressed upwards the knob *C* is rotated sl
until the plate is engaged by the screw threads; the
plate may then be fed in and so on until the magazine is
To prevent the top plate being crushed against the ro
the magazine when it reaches the ends of the threads a du
plate cut from sheet metal is inserted at the commence
of loading. When this dummy plate reaches the top i
prevents the further rotation of knob *C*, thereby indic
that the magazine is full. The operation is quite rapid
can be carried out easily under darkroom conditions.

PLATE ELEVATING PLATFORM

One feature of the present camera peculiar only to
electron diffraction application for which it was desig
the plate elevating platform *H*. In an electron micros
with its characteristic long focus this would not be neces
nor would it be likely to be warranted for other applica

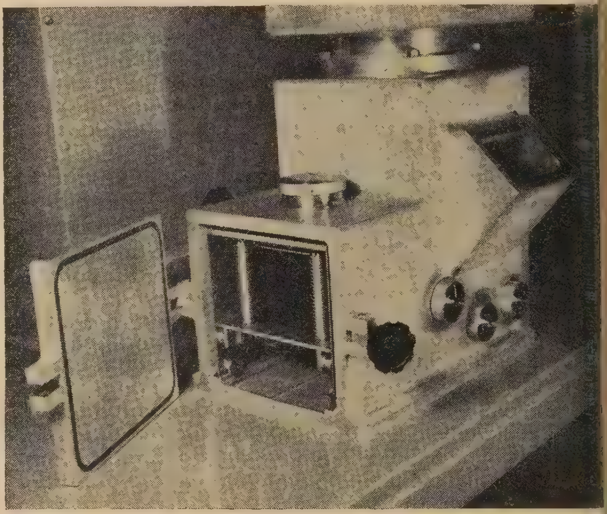


Fig. 3. View of vacuum chamber with loading do
open, showing fully loaded mechanism. The pla
collecting tray has been removed

For electron diffraction, however, this is desirable for
following reasons:

(1) The "camera length" of an electron diffract
apparatus, i.e. the distance from the specimen to
photographic emulsion, needs to be very preci
defined and to be constant from one exposure
another. By the use of the elevating platform
requirement is met because the position of the emuls
during exposure is defined only by the ledge of

aperture in the horizontal part of the partition *N* which is rigidly and permanently attached to the chamber walls. The camera length is unaffected by variations in the thicknesses of plates and in the positioning and adjustment of the magazine mechanism.

(2) The focus of the electron beam for electron diffraction work is fairly sharp and is adjusted by altering the current in the focus lens while observing the fluorescent screen. It is desirable, therefore, to bring the photographic emulsion as close as possible to the plane of the fluorescent screen for exposure. By the use of the plate elevating platform the separation distance of screen and emulsion has been reduced to 0·05 in.

CONCLUSIONS

The apparatus which has been described is believed to have e following advantages over earlier types of multiple-plate cuum cameras:$^{(1-4)}$

(1) The mechanism is relatively simple and reliable in operation. It has been in fairly continuous operation for a year and has given no trouble since its initial adjustments were made.

(2) The plate capacity is large and yet the chamber is very compact. The free volume of the camera compartment is 4 litres which is no greater than that of many cameras which hold only two or three plates.

(3) When the camera is initially loaded the plates are well separated, thereby greatly facilitating evacuation.

(4) The emulsions are not injured in any way in the course of handling the plates in the camera. Scuffing of emulsions was a particularly objectionable feature of some earlier multiple-plate cameras.

(5) There is only one position, accurately defined, in which the sensitive emulsions can locate for exposure. This adds to the precision and convenience of the camera in electron diffraction work.

Although the camera has been designed specifically for an electron diffraction apparatus it may be adapted with minor simplifying alterations for use in electron microscopes and high-speed cathode-ray oscillographs. It is probable also that the operating principle will prove useful in other applications of vacuum photography.

ACKNOWLEDGEMENTS

Our thanks are due to Prof. C. J. B. Clews for providing us with the facilities for carrying out this work, to Mr. D. W. Everson and his workshop staff for their contributions to the details of design and for their excellent craftsmanship, and to the C.S.I.R.O. for providing one of us (P. B. S.) with an Australian Post-Graduate Studentship. We also wish to express our indebtedness to Dr. F. A. Fox of the Defence Standards Laboratories, Victoria, for directing the making of patterns for and the casting of the vacuum chamber. Finally, we would like to thank Dr. R. I. Garrod of the Aeronautical Research Laboratories, Victoria, for drawing our attention to the excellent vacuum properties of silicon–aluminium castings.

REFERENCES

(1) Yearian, H. J., and Howe, J. D. *Rev. Sci. Instrum.*, **7**, p. 26 (1936).
(2) Fitzsimmons, K. E. *J. Opt. Soc. Amer.*, **28**, p. 437 (1938).
(3) Schulz, L. G. *Rev. Sci. Instrum.*, **15**, p. 78 (1944).
(4) Lafourcade, L., and Dargent, R. *J. Phys. Radium*, **13**, p. 274 (1952).

An automatic analyser of uranium content in process streams

By H. Bisby, B.Sc., A.M.I.E.E., and L. H. Brown, Atomic Energy Research Establishment, Harwell, Berks,
and D. R. Chapman, B.Sc., Grad.Inst.P., Baird and Tatlock (London) Ltd., Chadwell Heath, Essex

[*Paper first received* 7 *May, and in final form* 13 *August*, 1956]

The instruments described employ an absorptiometric technique for the determination of uranium-ion concentrations in aqueous solutions. Contemporary batch samples are taken in cyclic order from process streams, separately treated with aqueous ammonium thiocyanate, and the resulting colour complexes are analysed by an ultra-violet absorptiometer at 3650 Å. The cycle of events is entirely automatic and a permanent record of the uranium-ion concentration of the individual streams is produced. A four-point general-purpose analyser and a sixteen-point analyser for low (0·005 g/l.) concentrations of uranium are described in detail. The instrumental techniques evolved have wider applications in automatic chemical analysis.

e present importance attached to the extraction of uranium om naturally-bearing ores has led to the search for analytical chniques applicable to the assay of low concentrations of anium in aqueous solutions. Such solutions are encountered processes associated with ore leaching and subsequent ncentration of the acidic liquors, using for example an n-exchange column. In this process, uranium from the aching liquor feed to the column is adsorbed by ion-change on the resin bed during the adsorption phase and e output stream is normally barren of uranium, until the n-exchange zone reaches the outlet point, a condition own as "break-through." If the input to the column were aintained, the concentration of uranium in the output stream would gradually increase to that of the input pregnant liquor, or higher in certain circumstances. Practical considerations have formulated a break-through concentration at which the feed is discontinued. An almost similar break-through occurs when the uranium stored in the resin is taken off by elution but in this case the eluting liquor feed is maintained and the output stream diverted into a main-concentrate tank at elution break-through. As the elution proceeds a peak concentration is passed and diversion of the output stream is necessary as the concentration drops to pre-fixed levels comparable with that of the original pregnant liquor. These break-through and diversion points are shown on a typical ion-exchange column characteristic (Fig. 1).

A standard ion-exchange production unit comprises three columns operated in cyclic order, such that say column *A* receives pregnant liquor, whilst column *B* receives semi-pregnant liquor from column *A*, and column *C* is eluted, each column performing all three functions in turn. The barren output from column *B* is discharged to drain, whilst the eluate from column *C* is stored. The time taken for a complete cycle of operations on any one column is about forty hours. Control of these operations is often done on a volumetric basis aided by manual sampling and has proved satisfactory provided column performance remains normal, but conditions such as "channelling" and "poisoning" of the resin bed are known to occur, these causing premature adsorption break-through and inefficient elution. Present manual sampling/assay techniques are relatively slow, and substantial losses of uranium may be sustained during adsorption before a defect in column operation is detected. Inefficient elution or misdiversion of output streams may introduce dilution of the main concentrate and pregnant liquor tanks. Such losses and dilutions could be avoided by continuous or frequent monitoring of output streams, and it is with this in view that attention has been directed towards developing analytical and instrumental techniques which are applicable to the rapid assay of aqueous uranium solutions.

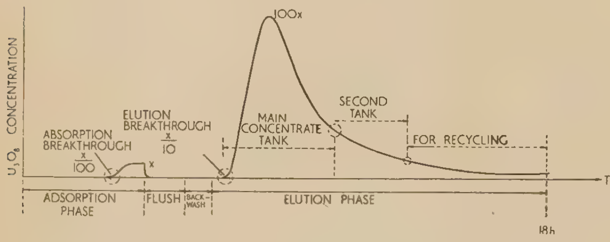


Fig. 1. Typical uranium output characteristics from ion-exchange column

x, pregnant liquor uranium concentration.

ANALYTICAL TECHNIQUE

Of the several techniques investigated for natural uranium assay such as radiometry, polarography and fluorimetry, none has been developed into a process instrument capable of a complete range from 0·005 to 50 g/l. The most promising technique at the time of this present development (April 1953) used the ultra-violet absorption by the colour complex which uranium forms with aqueous ammonium and potassium thiocyanates, and this present instrumentation is based on the results of an exhaustive investigation of the technique by Dr. R. E. Robinson and colleagues of the University of the Witwatersrand, Johannesburg, S. Africa, which are quoted below.

The logarithmic relationship between percentage transmission of ultra-violet light through the complex and the uranyl-ion concentration, was confirmed over the range 100–25% *T*, i.e.:

$$\log(\%T) = \log\left(\frac{I_s}{I_0} \times 100\right) = -kc \qquad (1)$$

where I_0 = light intensity through blank solution ($c = 0$),
I_s = light intensity through sample complex,
c = concentration of uranyl-ion,
k = constant for a given light path through complex.

Thus $\qquad d/dc(\%T) = -ke^{-kc}$

$$d/dc(\%T) \rightarrow \text{max. as } c \rightarrow 0$$

This implies that if the accuracy of measuring $\%T$ rem constant throughout 100–25%, the largest sensitivit achieved at the lower concentrations, e.g. at break-thro point in column operations.

The technique has the disadvantage that the presenc variable amounts of other ions such as ferric-iron, mangan magnesium, molybdenum, titanium, vanadium, chrom osmium and ruthenium may introduce a variable "bla since their thiocyanate complexes have absorption ba overlapping that chosen for uranium. The most ser interference of this nature arises from Fe^{+++}, how reduction to the non-interfering Fe^{++} can be rap achieved using acidified stannous chloride. Partic attention directed to the South African ores showed with this method, the loss of transmission contributed by main impurity ions Fe^{+++}, $Mg^{++}Mn^{++}SO_4''$ derived f any one process stream exhibited a deviation within limits to which percentage transmission could be meas i.e. $(T \pm 1)\%$ where $100 > T > 25$.

It was further shown that major variations in the concentration of the sampled liquors result in only mi changes in final pH of the mixture and conseque percentage transmission.

In two major respects, the technique offers a substan advantage for its application to automatic monitoring was shown that variations in the volumes of sample reagents up to ±5% did not affect the percentage tra mission within the limits quoted above. Another featur support is that the range of concentration covered by 1 25%*T* may be altered merely by the use of different con trations of complexing agent.

Table 1. *Effect of NH_4CNS concentration on range o uranium concentration*

(100 $T\%$ 25)

NH_4CNS *%w/v*	*U_3O_8* *(g/l.)*
50	0–0·05
30	0–0·10
20	0–0·15
15	0–0·21
10	0–0·34
5	0–0·74
3	0–3·50

MONITORING FOR PLANT OPERATIONS

A preliminary experimental equipment by Robins operating with continuous flow, gave sufficiently promis results to warrant further development of the technique full-scale plant monitoring. Two basic requirements uranium monitoring are predominant in large-scale operat of multiple sets of three-column ion-exchange units. T most vital of these is to actuate an alarm system should uranium concentration exceed a pre-fixed low operatio level in the "barren" output stream from any of the un This alarm will safeguard against loss of uranium due faulty column performance and indicate the occurrence adsorption break-through. The second requirement is monitor barren, semi-pregnant and elution output strea from a single three-column unit together with the inp pregnant solution, thereby obtaining detailed informati n adsorption and elution efficiencies under the operating onditions defined by the time/volumetric control system. 'he latter is the most exacting requirement owing to the wide ange of uranium concentrations to be dealt with (Fig. 1). Jevertheless, it was thought that an instrumental technique roved satisfactory for this purpose could be readily extended) the former, which involves samples with similar low con-entrations only. Furthermore, the successful development f such an instrument offers the possibility of completely utomatic control of a three-column unit.

The first instrument (Mk. I) was therefore designed for our-point sampling, two-range monitoring and accurate irect recording of concentration. It has been successfully perated on a production plant both for investigation of unit ehaviour and as a three-barren monitor, and has provided aluable information and experience to guide the design of a Ak. II instrument for monitoring up to sixteen process reams. The Mk. II instrument incorporates the same echniques for batch sampling, sample treatment and analysis, ut with increased reliability and at double the previous ample-handling rate, a factor of considerable importance 'hen a large number of output streams require frequent nalysis. In this application, operation of an alarm system regarded as more important than the recording of con-entration directly in grammes per litre, although the accuracy f measurement and recording has not been relaxed.

MONITORING TECHNIQUE

Although the cycle of column operations is relatively slow, ie benefits of a minimum "analysis delay" are obvious for ulti-stream monitoring. With continuous-flow principles iis delay is seldom less than ten minutes owing to the iherent difficulty of complete displacement of even small ample volumes. A technique of batch sampling from con-nuous flow was therefore developed which, although emanding larger sample volumes to achieve accurate roportioning of sample with reagents, reduced this delay) five minutes and later to two minutes, so that very frequent spot" assays of several process streams became possible. 'his multi-point batch sampling, using common apparatus, itroduced some difficulties in ensuring that:

(i) the sample was contemporarily representative of the process stream condition, and
(ii) contamination of one sample by its predecessor was small compared with the detection sensitivity of the analytical method.

'he first of these was solved by keeping the volume of the ampling pipes to a minimum consistent with working ressures and desired flow rates, and by flushing the stale quor from the pipe through the apparatus before sampling. 'he latter procedure also assisted with the second problem y removing any residual liquids in valves and tubing which ad been held over from previous analyses. In addition utomatic washing of common apparatus with water was itroduced between samples.

The analytical method requires that a fixed volume of ample should be added to an equal volume of ammonium iiocyanate solution of known concentration and a one-fth volume of 50% w/v stannous chloride in hydrochloric cid. These must then be thoroughly mixed to complete the eduction of ferric-ion, and produce a homogeneous colour omplex before being discharged into the measuring cell of ie absorptiometer. The flow of samples and reagents into ie apparatus was controlled by electromagnetically-operated diaphragm valves. Volume proportioning was achieved by a system of "capacitance probes" situated at pre-fixed heights up the cylindrical measuring vessel (Fig. 2). These probes cause the appropriate electromagnetic valves to close.

After automatically complexing the mixture of sample and reagents by air agitation, the final liquid must be discharged into the absorptiometer, its %T measured, and the measuring cell and mixing vessel washed out in preparation for the next sample. The times required for these individual operations cannot be reduced below certain values, but the effective time between successive analyses was reduced by arranging for operations to be done concurrently. To this end, two absorptiometer measuring cells (cells A and B) were used and successive complexes discharged into them alternately, thereby overlapping the measurement on one cell with the washing of the mixing vessel and alternate cell. This principle was later extended to overlap the analysis of one sample with the flushing of the subsequent sample feed pipe.

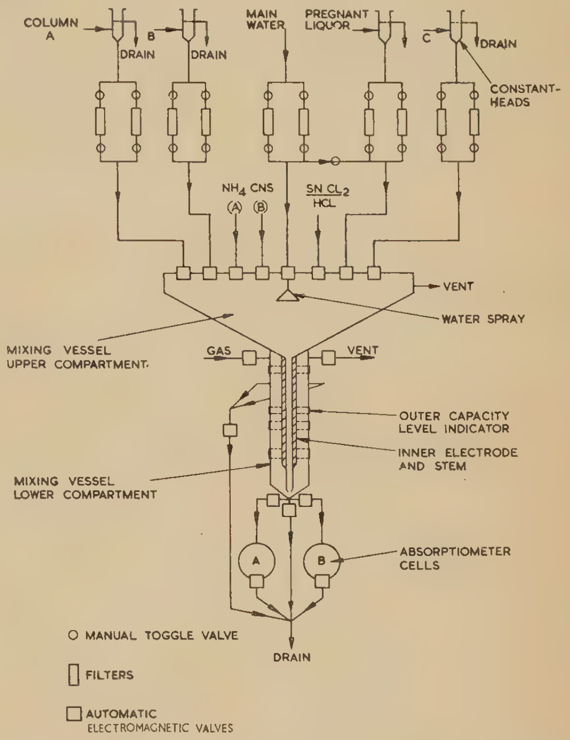


Fig. 2. Schematic diagram of Mk. I analyser apparatus

To provide accurate (±1%) determination of %T it is essential for the absorptiometer to have beam compensation or standardization. This requirement, in addition to that of using two fixed sample cells, led to the development of a novel absorptiometer in which the same light beam is made to pass through cells A and B and a reference cell in cyclic order. A d.c. voltage proportional to the intensity of the light falling on the detector after passing through each of the three cells is produced and the voltage ratios V_A/V_{ref}, and V_B/V_{ref} measure the percentage transmissions through the two sample cells, when V_{ref} has been electrically adjusted equal to V_{blank}, and are thus related to uranyl-ion concentrations in the samples. The range of uranium concentration associated with each strength of ammonium thiocyanate solution is limited (Table 1), and consequently, to provide comparable sensitivities for very low and much higher concentrations of uranium, the facility for complexing the sample with one of two solutions of ammonium thiocyanate was incorporated.

Apart from creating a permanent time record of the percentage transmissions of successive samples from the various sources, a visual indication is needed to integrate the instrument information with the manual control of the plant. The principle of using a graphic panel with lamp indication was therefore applied to show which sampling point is under investigation, and which of two range scales should be read off the recorder. The recorder of the Mk. I instrument has colour identification of the sampling points. For the sixteen-point instrument (Mk. II) colour identification is not feasible and a method of pulse-coding the record was used.

DESCRIPTION OF ANALYSER MK.I

The characteristics of this instrument may be briefly summarized as follows.

(*a*) Four sample-point monitoring in cyclic order is possible under completely automatic or manual control. Each sample-point is identified both visually and on the permanent record.

(*b*) The automatic sequence of operations performed on any one sample-point is set out in Table 2. A full sequence takes five minutes, but this is reduced by one minute if the repeat sample is not taken (see below). A complete cycle on four sample-points cannot exceed twenty minutes, and is likely to take about sixteen minutes when monitoring barren streams.

(*c*) Two ranges of uranium concentration are automatically covered by complexing a repeat sample with weaker ammoniun thiocyanate (concentration *B*) during operations 13–17. These operations are cancelled if the %T of the original sample complex is between 100 and 25%. The ranges are readily identified on the recorder chart by the time occurrence of deflexions. The range scales on the recorder are coloured to correspond with the two coloured range lamps on the graphic panel.

(*d*) Any sample-point can be omitted from the cycle by selection; furthermore, if a column feeding any sample-point is neither on adsorption nor on elution that point is automatically omitted.

(*e*) Several facilities assist in routine maintenance and safeguard against defective operation:

(i) drip trays of stainless steel are provided for each compartment where maintenance involves disconnexion of pipes. The trays are connected to a common drain;

(ii) sample and water lines have twin filter systems, to allow uninterrupted operation during filter maintenance,

(iii) a shut-down wash of mixing vessel and absorptiometer cells is performed automatically (operations 22–25) if the instrument is instructed to stop cycling at any time during a sequence, otherwise these operations are omitted;

(iv) an "emergency drain" condition can be initiated manually, when all drain valves are opened and the sequence is put to the "wait" conditions;

(v) a fault-alarm system operates whevever the sequence is detained on any one of its operations for longer than a pre-set time. This system energizes a warning bell and red light, opens all drain valves, closes all inlet valves, and holds the sequence-controlling mechanism on the position at which the fault occurred. The position can be readily found by a manual sea switch;

(vi) an interruption of the a.c. mains supply of longer t 40 ms breaks the d.c. supply to close all valves, ther preventing flooding during the interruption. The supply is automatically reconnected after a one mi delay, on restoration of the a.c. supply, and sequence of operations continues.

Table 2. *Sequence of operations for Mk. I analyser*

No.	*Operations*			*Tim*
1	Change sampling point			
2	Flush stale liquor in feed pipe through mixing vessel to drain	Drain cell *B*		
3	Drain mixing vessel			
4	Accumulate sample in mixing vessel (40 ml.)			
5	Add ammonium thiocyanate (conc. *A*) (40 ml.)			
6	Add acid stannous chloride (8 ml.)			
7	Mix, using hydrogen or air, to develop complex			
8	Discharge complex into absorptiometer cell *A*			
9	Wash mixing vessel with water	View cell *A*	and record %T	
10	Discharge water in mixing vessel *via* absorptiometer cell *B* to drain	View cell *A*		
11	Repeat operation 9	View cell *A*		
12	Repeat operation 10	View cell *A*		
13	Accumulate repeat sample in mixing vessel (40 ml.)			
14	Add ammonium thiocyanate (conc. *B*) (40 ml.)			
15	Repeat operation 6			
16	Repeat operation 7			
17	Discharge complex into absorptiometer cell *B*	Drain cell *A*		
18	Wash mixing vessel with water	View cell *B*	and record %T	
19	Discharge water in mixing vessel *via* cell *A* to drain	View cell *B*		
20	Repeat operation 18	View cell *B*		
21	Repeat operation 19	View cell *B*		
22	Drain cells *A* and *B*			
23	Wash mixing vessel, discharging water *via* cells *A* and *B* to drain			
24	Drain cells *A* and *B*			
25	Wait for further cycling instructions			
		Total sequence time per sample		29 or 24

Fig. 3 shows the console form of the complete appara comprising the liquid-handling system, electronic and au matic control units, absorptiometer, graphic panel a recorder. Each separate unit is easily removable for servici The graphic panel at top left has four lights identifying sampling points, two range lights, and other lights denot e various events in the automatic sequence. Immediately low this is the control panel fitted with meters, manual ntrol switches and visual fault alarm indicator, the sequence ntrol unit which programmes the operations to be per- rmed, and below this the timing pulse unit. The bottom it on the left is the power unit for the absorptiometer which

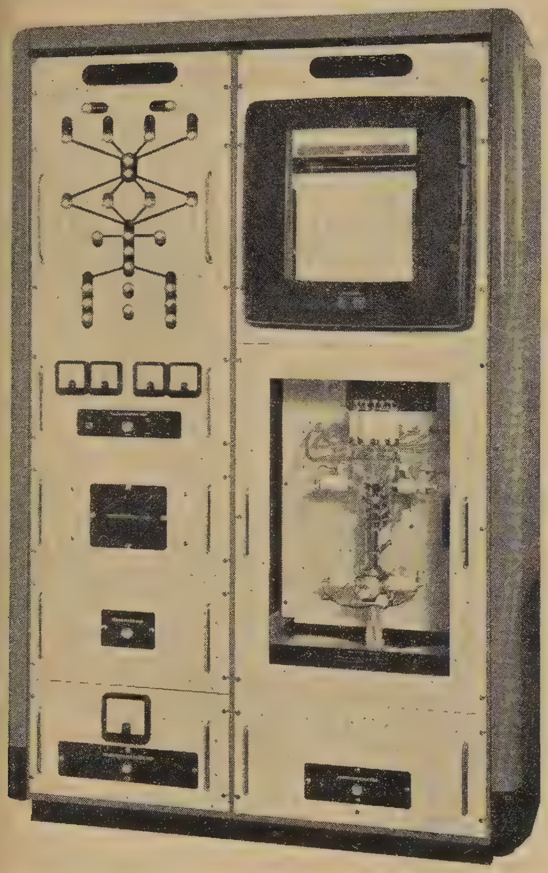


Fig. 3. Mk. I analyser console

immediately to its right. The mixing vessel compartment internally illuminated so that operations can be seen rough the Perspex window.

Reagents, sample liquors and wash-water, enter the console n the top face *via* pipe connectors which are guarded by a rip-tray. The sample liquor and water lines proceed through e filter system (Fig. 2), situated behind the graphic panel, the mixing vessel, in which sample and reagent propor- oning and mixing is done and from which the complex is ischarged into the absorptiometer. A common drain is tuated on the underside of the console. Apart from its onstitution in console form, the apparatus is not protected gainst dust or accidental spraying by plant liquids, although pen-type relays are enclosed in dust-proof boxes. It was lt that such protection could best be obtained by installing e analyser in a dust- and liquid-proof cubicle with windows nd doors to provide for observation and maintenance.

Fig. 2 is a schematic diagram of the liquid-handling pparatus. The sample inlet points are connected to the ion- change column outlets *via* simple "constant-head" units perating on an overflow principle. This proved a ready eans of evading surges and wide variations (25–65 lb/in.^{2}) column output pressure. The filters consisting of porous ceramic disks of 10 μ pore size, minimize particle light-scatter in the absorptiometer. Isolation of any filter, e.g. for cleaning, is achieved by closing the appropriate toggle-operated diaphragm valves, and by similar means a water sample can be introduced instead of a pregnant liquor sample to obtain a reagent-blank. Each liquid line is terminated by an electromagnetically-operated diaphragm valve on the mixing vessel head, and flow of any liquid can be started by energizing the appropriate valve solenoid. Incoming liquid falls on to the sloping interior of the upper funnel-shaped compartment and accumulates in the lower glass cylindrical compartment after passing down the stem of the funnel.

Referring to Fig. 4 the funnel stem is formed from two concentric glass cylinders, the annular space between them

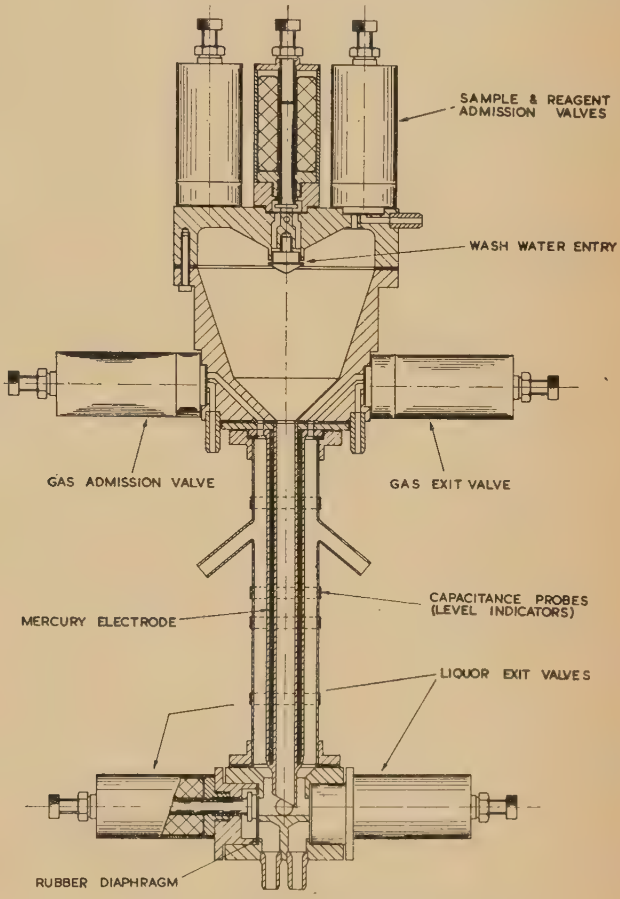


Fig. 4. General assembly drawing of mixing vessel

being filled with mercury which acts as the central (earthed) electrode for the outer concentric electrodes of the capacity probe level indicators, and at the same time electrically screens these from incoming liquid falling down the stem. The outer electrodes are thin chromium-plated copper bands, 0·6 cm wide, clamped round the outside of the lower compartment at pre-set heights. As the liquid level enters the 0·6 cm dimension of these electrodes their capacitance to earth rapidly increases (approximately 5 pF/mm) until a value is reached which is sufficient to unbalance a capacitance bridge and operate a relay. Four such electrodes are used, namely, for sample, ammonium thiocyanate, stannous chloride and water; the latter prevents accidental flooding of the mixing vessel during the washing process, in which water is sprayed on to the interior wall of the upper compartment, flushes down the stem and swirls up the lower compartment to "weir" out through the two overflow pipes to drain.

The lower compartment has three drainage valves, an air inlet and an air-vent valve. Mixing of the sample and reagents is done by opening the air valve and closing the air vent, when the air pressure forces the liquid from the lower compartment into the upper compartment *via* the stem; agitation of the liquid then ensues, the air bubbling through it and escaping *via* the permanent vent in the head.(1)

All valves in the system are of the same basic design chosen for positive action, small hold-up volume and rapid operation.(2) Each comprises a circular acid-resisting rubber diaphragm bonded to a steel plunger (Fig. 4) which is pressed against the liquid inlet port by a spring. The plunger is withdrawn from the valve ports against the action of the spring to permit liquid flow. To avoid difficulties in alinement between plunger, diaphragm and ports, the diaphragm is thickened over an area covering the ports to make a compressible pad which forms itself to the port configuration under the spring pressure. The plunger is lifted manually in valves associated with the filters and electromagnetically using a solenoid in those needed to be automatically operated. The valve hold-up volume is less than 0·1 ml. and the release time about 30 ms. Liquid admittance valves with $\frac{1}{8}$ in. bore ports will withstand an input pressure of 20 lb/in^2.

Great care has been taken throughout to ensure a degree of self-draining (better than 1 ml.) consistent with the problem of carry-over from sample to sample.

For the 1% accuracy of measuring %T required in this application, it is usual to provide a reference cell containing a reagent blank and compare the absorption in this with that in the sample under analysis. Techniques for doing this involve multiple beams and their inherent complications, or a single beam instrument and a substitution method which does not lend itself to continuous-flow or high-speed batch analysis. These disadvantages are overcome and the additional requirement for two fixed sample cells met, by causing a single beam to scan three identical cells.(3) Two parallel rhombs, arranged as in Fig. 5 so as to rotate about the light source-detector axis, cause the path of the light beam to rotate about this axis, meanwhile remaining parallel to it. The three cells are placed in the circular locus of the offset beam so that it passes successively through the cells over fixed arcs. The ultra-violet band is selected by a filter covering the window of an end-sensitive photomulti whose voltage output after amplification is switched into t voltage integrator systems by a commutator on the rho rotor shaft. A rotation speed of 10 c/s was chosen to the time constant of the storage network small, yet l relative to the pulse recurrence frequency. Cells and rho are constructed from Perspex and highly polished. sample cells are designed to take the full complex vol (88 ml.) and are scanned over 30° of arc as is the refer cell. All three cells interpose the same thickness of Per in the light beam and have a 1 cm liquid path. Each sa cell is fitted with an air vent, an electromagnetically-oper diaphragm valve situated so that complete self-drainin possible, and a removable window for easy cleaning.

The programme sequencing circuit employs an eight- twenty-five way uniselector associated with twenty-six rel and the circuit design is based on the principle that e operation must be completed (time or capacitance-r control) before the uniselector wiper is driven on to ini the next operation. A relay pulse scaler (÷16) is supp with 50 V pulses generated every two seconds by a ecmhanism on the shaft of a 50 c/s synchronous moto the time pulse unit. The scaler puts out a pulse delaye $2n_1$ seconds from the commencement of scaling, where may be selected from 1 to 15. This time interval is used controlling operations 3, 8, 9, 10, 11, 12, 18 to 24 (Table By injecting pulses at four-second intervals, generated another cam system, the delay period can be extended $4n_2$ seconds where n_2 may be selected from 1 to 15. T longer interval is used on operations 2, 7 and 16 (Table

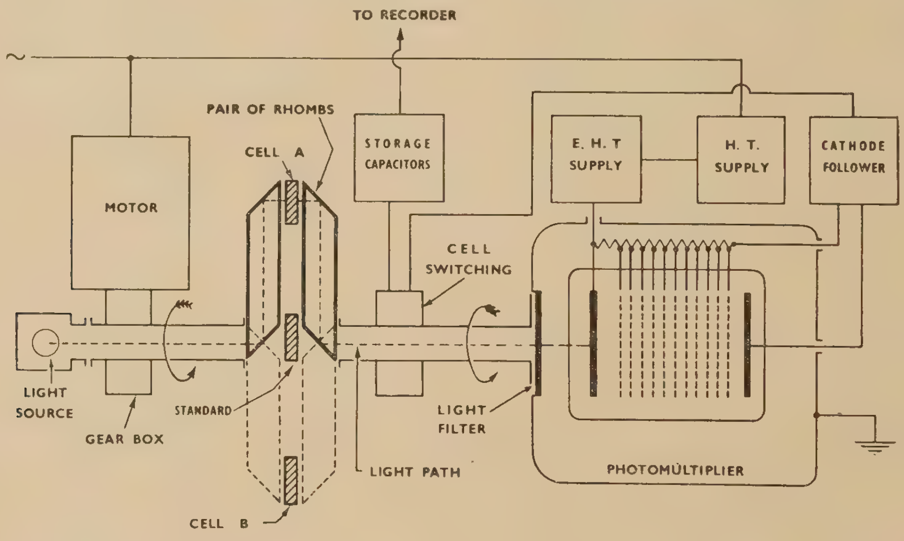


Fig. 5. Schematic diagram of absorptiometer unit

The scaler is reset for each new position of the uniselec wiper, but should the scaler not be reset before the exp of 2 × 16 (or 4 × 16) seconds the fault alarm system opera

DESCRIPTION OF ANALYSER MK. II

The function of this instrument has been discussed earli when it was implied that the problem of contaminati between one sample complex and its predecessor would be so serious, since only streams carrying almost like conc trations of uranium are to be monitored; these may "barren" or "semi-pregnant" streams. The main probl was to increase the sample handling rate and to identify sampling point with its result of analysis on the permane record.

Table 3. *Sequence of operations for Mk. II analyser*

No.	Operations			Time (s)
	Flush feed pipe from auxiliary head 2 to drain *via* mixing vessel	View cell *B* which contains complex from previous sample		12
	Accumulate new sample in mixing vessel (15 ml.)	View cell *B*		3
	Add acid stannous chloride (3 ml.)	View cell *B*	Flush next sample-point to drain *via* auxiliary head 1	1
	Add ammonium thiocyanate (conc.A) (15 ml.)	View cell *B*	Flush (continued)	3
	Mix sample and reagents in upper compartment of mixing vessel	View cell *B*	Flush (continued)	12
	Release mixture into lower compartment of mixing vessel	View cell *B*	Flush (continued)	12
	Complete mixing in upper compartment	View cell *B*	Flush (continued)	36
	Discharge complex into absorptiometer cell *A*	Drain cell *B*	Flush (continued)	12
	Wash mixing vessel to drain *via* cell *B*	View cell *A*	Flush (continued)	12
	Wait if instructed to do so during operations 11 to 25 of previous sequence			
d	Change sample-point	View cell *A*	Flush (continued)	12
			Carried forward	115
			Brought forward	115
13	Flush feed pipe from auxiliary head 1 to drain *via* mixing vessel	View cell *A*		12
14	Accumulate new sample in mixing vessel (15 ml.)	View cell *A*		3
15	Add acid stannous chloride (3 ml.)	View cell *A*	Flush next sample-point to drain *via* auxiliary head 2	1
16	Add ammonium thiocyanate (conc. *A* or *B*) (15 ml.)	View cell *A*	Flush (continued)	3
17	Mix sample and reagents in upper compartment of mixing vessel	View cell *A*	Flush (continued)	12
18	Release mixture into lower compartment of mixing vessel	View cell *A*	Flush (continued)	12
19	Complete mixing in upper compartment	View cell *A*	Flush (continued)	36
20	Discharge complex into absorptiometer cell *B*	Drain cell *A*	Flush (continued)	12
21	Wash out mixing vessel to drain *via* cell *A*	View cell *B*	Flush (continued)	12
22	Wait if instructed to do so during operations 1–10			
23 to 25	Change sampling point	View cell *B*	Flush (continued)	—
	Total sequence time per two samples			218 s

The scheme adopted for the sequence of operations per- rmed on a given sampling point is detailed in Table 3. The inciple of concurrently operating on a previous sample mplex, a present sample and the liquor to be next sampled set out. Operations 1–25 now cover the assay of two mpling points in less time than the Mk. I instrument took r one assay.

Fig. 6 is a schematic diagram of the liquid handling paratus showing the addition of two auxiliary heads and moval of filters from the console to the external constant-ad compartment. The purpose of each auxiliary head, art from being a junction point for multi-point inputs, is enable the stale liquor in the feedpipe from the constant ad device to flush to drain whilst the sample taken from e previous sampling point *via* the other auxiliary head is ing "complexed" (Table 3). The time available for flushing now about 2 min (44 s in Mk. I) which will permit the strument to be disposed at least 60 ft from the constant-ad compartment for plant operating convenience. The xiliary heads are to the basic design of the mixing vessel ad and each is fitted with eight electromagnetic valves.

The characteristics of this instrument differ from those of k. I in the following respects only.

(*a*) A maximum of sixteen sample-points can be monitored in cyclic order under completely automatic or manual control.

(*b*) Any number of sample-points can be omitted from the cycle by selection, and this does not materially alter the time interval between successive sampling of any one point.

(*c*) Samples can be "complexed" with one of two ammonium thiocyanate concentrations by preselection.

(*d*) The permanent record produced by each assay presents two deflexions which are a measure of V_{ref} and V_A (or V_B).

(*e*) In addition to the fault-alarm system, a concentration-alarm system operates if V_A or V_B is less than a pre-fixed percentage of V_{ref}, this ratio corresponding to normal adsorption break-through concentration. An immediate check to establish that the sampled stream is exceeding the concentration-alarm level may be made by cancelling the alarm and instructing the instrument to take a repeat sample, the complex of which is analysed in the alternative absorptiometer cell.

(*f*) The instrument may at any time be set to stop cycling. The sample complexing operations being performed are completed but the next sample is omitted whilst recording the result of analysis. The instrument then rests in the "wait" condition (operations 10 and 22, Table 3).

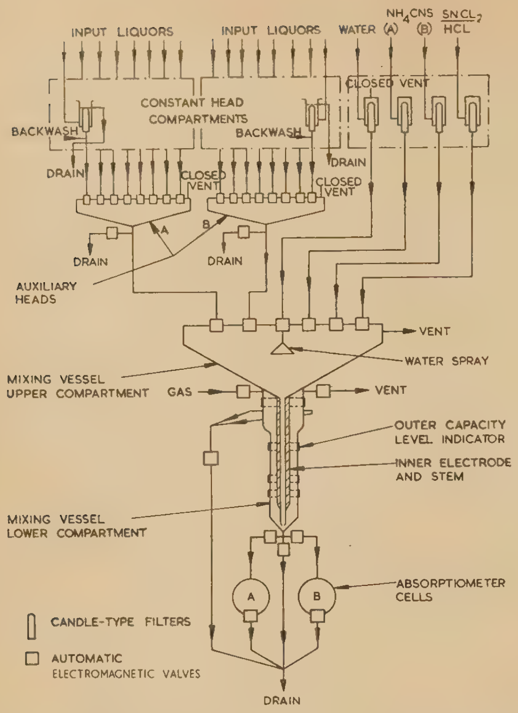

INPUT LIQUORS
INPUT LIQUORS
WATER
NH4CNS (A)
(B)
SNCL2 / HCL
CLOSED VENT
CONSTANT HEAD COMPARTMENTS
BACKWASH
BACKWASH
DRAIN
DRAIN
CLOSED VENT
CLOSED VENT
A
B
DRAIN
DRAIN
AUXILIARY HEADS
VENT
WATER SPRAY
MIXING VESSEL UPPER COMPARTMENT
GAS
VENT
OUTER CAPACITY LEVEL INDICATOR
INNER ELECTRODE AND STEM
MIXING VESSEL LOWER COMPARTMENT
A
B
ABSORPTIOMETER CELLS
CANDLE-TYPE FILTERS
AUTOMATIC ELECTROMAGNETIC VALVES
DRAIN

Fig. 6. Schematic diagram of Mk. II analyser apparatus

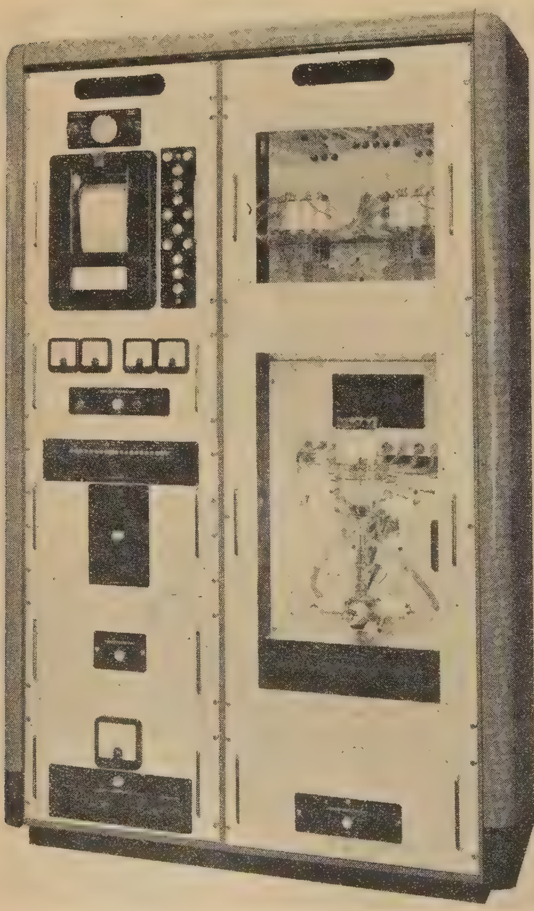


Fig. 7. Mk. II analyser console

The assembly of the Mk. II instrument (Fig. 7) is sim to that of Mk. I. The auxiliary heads are situated above mixing compartment, and the recorder is combined with graphic panel to form a display panel on which the seque lamps, fault- and concentration-alarm indicators are moun Visual identification of sample-point is provided on the sequence control unit.

Liquor lines to the constant-head compartment continuo bleed off a fraction of the process stream, the flow-de being determined by the length of pipe from the column the flow rate which can be tolerated. Samples pass to auxiliary heads through the ceramic "candle" type fil (Fig. 6) of porosity about 7 μ, and excess liquor "we out of the constant-head unit to a collecting tank. arrangement allows the filters to be back-washed with wa at suitable pressure, which process also removes air lo which may accumulate in the filters. Similar filters included in reagent and wash-water lines.

The lower compartment ("measuring cylinder") of mixing vessel is re-designed to reduce the volumes of sam and reagents used per assay to 15, 15 and 3 ml.

The milliampere recorder is normally deflected to V_{ref}. When a sample complex is viewed by the absorp meter it reads V_A or V_B as appropriate, and the record appe with V_A or V_B as deflexions from a base line given by This permits an easy visual check of an analysis, since increase in uranium concentration is displayed as an incre in deflexion from the base line, and provides accurate inf mation for subsequent analysis of results. The deflex corresponding to any specific sample-point is identified switching the recorder from V_{ref} to V_A (or V_B) at a num of two-second intervals equal to the identification number the sample-point. V_{ref} is held at a constant value independ of slow drifts in light source output, photomultiplier ex high-tension voltage, etc., by a feedback circuit in wh V_{ref} effects control on the extra high-tension voltage.

PERFORMANCE AND RESULTS

Early tests on the repeatability of volume measurement the mixing vessel showed that the deviations obtained w far greater than was to be expected from the detection s sitivity of the capacitance level indicator system, and we in fact, incurred by a combination of varying rates of liq inflow and the delay between actuating the level indica system and sealing the inlet port. With this delay cut t minimum, volume accuracy was $\pm 0{\cdot}25$ ml. at a flow r of 8 ml./s, being proportionately better for slower flow.

Reagent concentrations and volume proportions reco mended by Robinson were used, the actual quantities be as already stated. A mixing time of 45 s, using air agitati was found necessary to ensure complete reduction of fer ion (5 g/l.) and development of complex. The ultra-vi filter in the absorptiometer was a Chance type OX 1A peak at 3650 Å and with half-width 300 Å.

A typical calibration curve obtained with the analy using 10% w/v ammonium thiocyanate shows the relations between uranium concentration and percentage transmiss (Fig. 8). The accuracy to which $\%T$ can be measured approximately $\pm 1\%$ so that $0{\cdot}1$ g/l. can be determined $\pm 3{\cdot}5\%$, and the smallest detectable change of concentrati assuming a blank of $95\%T$, will be $0{\cdot}002$ g/l. With 50% w/v ammonium thiocyanate solution the reagent bla gave $80\%T$ and $0{\cdot}005$ g/l. gave $70\%T$, i.e. a theoreti minimum detectable concentration change of $0{\cdot}0004$ g/l.

To check the extent of carry-over between success samples a 25 g/l. uranium sample was taken automatica nd followed by a distilled water sample. The latter produced blank of 98% with 20% w/v ammonium thiocyanate, orresponding to a carry-over factor of 8×10^{-5}.

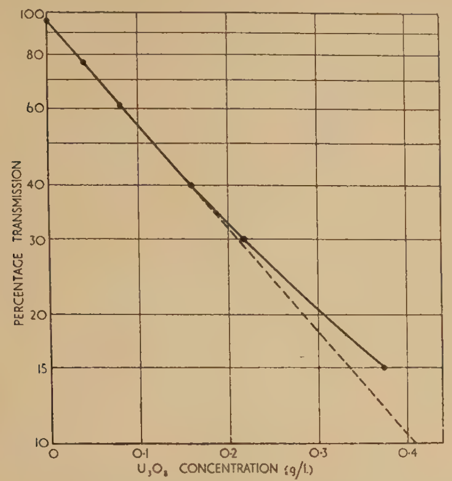


Fig. 8. Calibration curve for Mk. I analyser using 10% w/v NH_4CNS

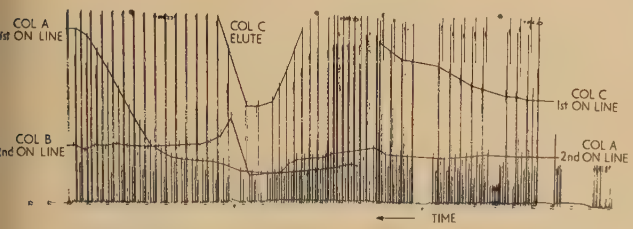


Fig. 9. Typical Mk. I analyser record

Fig. 9 is a black and white reproduction of a typical record btained with the Mk. I instrument during plant operation. he recorder deflects from zero only during the time interval n which the absorptiometer is comparing the complex with he reference solution, causing a series of coloured flatopped peaks [a single peak if only the first range (*A*) is used, nd two peaks if both ranges (*A* and *B*) are used]. To show he trend of variation of uranium concentration, black lines oining similarly coloured peaks have been superimposed on he record. These clearly show the build-up of column *C* output (semi-pregnant) to pregnant liquor concentration, and break-through on column *A* (barren) at which point loading of columns *A* and *C* was stopped for flushing and back-wash operations. The record then shows part of the semi-pregnant build-up on column *A*, and the "royal barren" obtained when column *B* first receives semi-pregnant liquor from column *A*.

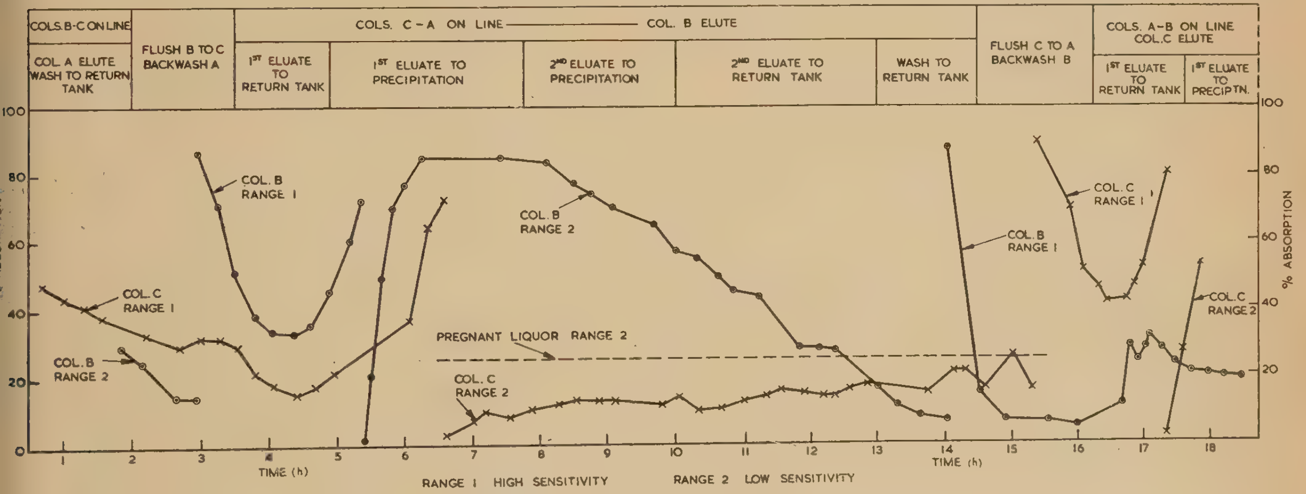


Fig. 10. Record analysis of three-column unit operation

A record analysis of the cycle of operations on a three column unit (Fig. 10) gives an indication of the detail which is possible with the instrument. The performance of the instrument in monitoring three barren streams and one reagent blank has been reported by Veldthuis of the University of Witwatersrand, and reveals the considerable value of the instrument in preventing losses of uranium through the "barren" solutions. A practical level for break-through detection is quoted as 0·003 g/l.

The Mk. II analyser embodies techniques which have been proved under plant conditions and improvements based on experience gained. Its main function, to monitor barren solutions for premature and normal adsorption break-through, remains to be tested under operational conditions and there seems little doubt that its performance will be satisfactory.

ACKNOWLEDGEMENTS

The instruments described in this paper have been constructed by members of both the Electronics Division, Atomic Energy Research Establishment, Harwell, and the Research and Development Division of Baird and Tatlock (London) Ltd. The authors wish to express their indebtedness to Prof. L. Taverner, Government Metallurgical Laboratory, University of the Witwatersrand, Johannesburg, for his valuable advice, Mr. R. G. Velthuis for his assistance in South Africa and together with staff of the West Rand Consolidated Mines Ltd., and D. Drury and Co. Ltd., Johannesburg, for their co-operation in the installation and operation of the equipment. Thanks are also due to the Director of the Atomic Energy Research Establishment and the Directors of Baird and Tatlock (London) Ltd., for their permission to publish this paper.

REFERENCES

(1) British Patent Application 17445/55.
(2) British Patent Application 36704/55.
(3) British Patent Application 19462/55.

On the reduction of the dark current of photomultipliers

By Zs. Náray, Central Research Institute for Physics, Budapest

[*Paper received* 17 *October*, 1955]

Two methods are used for reducing the rate of dark current pulses of photomultipliers; the reduction is equivalent to a cooling of about 100° C. The two methods are: the reduction of the sensitive area of the photocathode and the application of a suitable shield potential to a layer on the outer surface of the envelope.

In the course of the investigation of the shield effect the stability conditions of the multiplier and the effect of the shield potential on the pulse height distribution were studied.

The minimum light intensity which can be measured by photomultipliers is determined by the rate of dark current pulses. Cooling is often used to reduce the rate of dark current pulses(1,2) but this may reduce the sensitivity of the photocathode.(1)* Also, cooling is rather cumbersome and by reason of the thermal disturbances caused, its application is not always possible (e.g. interferometry).

In this paper two alternative methods, replacing cooling at least in part, will be described which can be applied to commercially available multipliers (RCA-931-A and Mazda 27M1). They are: the reduction of the sensitive area of the photocathode and the application of a suitable shield potential to a layer on the outer surface of the envelope.

Although the efficiency of these methods varies with the individual multipliers the variations do not exceed those of other characteristics.

FIRST METHOD

When a light beam falls on the photocathode of a multiplier the pulses appearing on the anode consist of two components: the pulses produced by photoelectrons emerging from the illuminated part of the cathode surface and the dark current pulses arising from the total cathode surface. When the illuminated area is smaller than the whole cathode surface it is possible to reduce the number of dark current pulses by preventing the electrons emerging from the non-illuminated part of the photocathode from reaching the anode and thus producing output pulses. Defocusing was introduced into the electrode system to achieve this and controlled for any point on the photocathode.

Using this method the minimum rate of dark current pulses at a given light intensity is obtained by focusing the light to a single point on the photocathode and defocusing all electrons emerging from other points. Since the minimum area of a photocathode on which the light can be focused depends on the optical arrangement, defocusing has to be extended over surfaces of variable size and shape. The effect of defocusing can be checked by measuring the apparent sensitivity of the multiplier at various points of the photocathode(3), as the apparent sensitivity depends on the sensitivity of the photocathode and the focusing efficiency between photocathode and anode.

Defocusing in a direction perpendicular to the symmetry axis of the multiplier can be achieved by applying suitable voltages to the dynodes of the multiplier. The sensitivity distributions on the photocathode in the normal and defocused cases are shown in Fig. 1.

In a direction parallel to the symmetry axis of the multiplier, magnetic defocusing is used. In Fig. 2 the sensitivity distributions in the normal and defocused cases are shown in addition to the arrangement of the magnets. The inte bias curve of dark current pulses under normal conditi and for horizontal and vertical defocusing are illustratec Fig. 3, and it can be seen that the dark current pulse rate f under the influence of defocusing in horizontal and vert directions simultaneously by one order of magnitude wh corresponds to a cooling of about 35° C; at the same ti the shape of the integral bias curve is also altered.

Another advantage of the defocusing method becam apparent when the multiplier was supplied by high volta pulses of about 5 kV. The field emission, especially fro the sharp edges and corners of the photocathode and the fi dynodes, contributed considerably to the formation of t

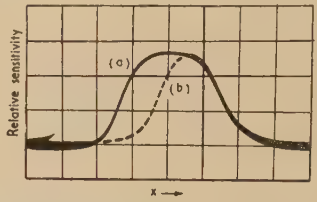


Fig. 1. Oscillogram showing the sensitivity distributio in the x-direction (perpendicular to the symmetry axis o the multiplier). Curve *a*, normal sensitivity distributio Curve *b*, defocused sensitivity distribution

	Curve a	*b Curve*
Supply voltage	−1000 V	−1000 V
Voltage between cathode and dynode number 1	100 V	60 V
Voltage between cathode and dynode number 2	200 V	200 V
Voltage between cathode and dynode number 3	300 V	300 V

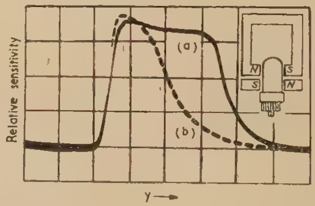


Fig. 2. Oscillogram showing the sensitivity distribution in the y-direction (parallel to the symmetry axis of the multiplier). Curve *a*, normal sensitivity distribution; Curve *b*, defocused sensitivity distribution. The arrangement of the defocusing magnets is also shown. The lower magnet lies in a plane perpendicular to the plane of the figure. To simplify the curves the effects of the grid in front of the photocathode(3) are smoothed out by optical means

	Curve a	*Curve b*
Supply voltage	−1000 V	−1000 V
Magnetic field	not applied	applied

---

* Note added in proof: Investigations carried out by us recently have shown that using caesium-antimony photocathodes the sensitivity decreases by one order of magnitude when cooling from room temperature to −170° C.

rk current and these electrons were prevented by defocusing om reaching the anode, and this essential component of the rk current reduced.

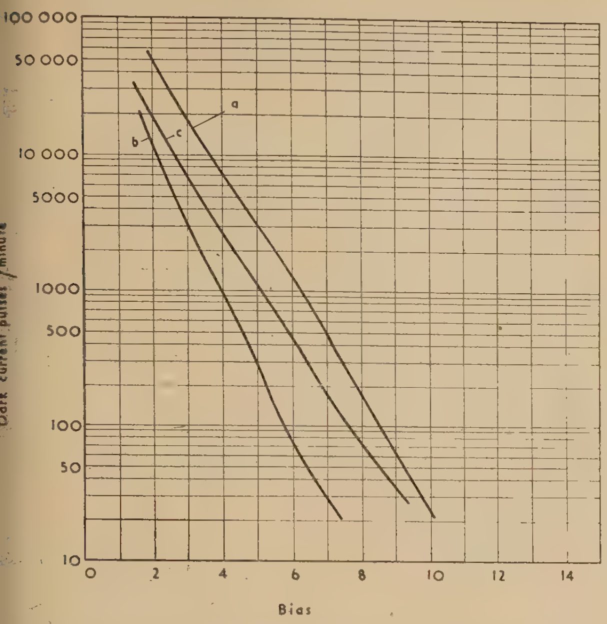


Fig. 3. Integral bias curve of the dark current pulses. Curve *a*, normal case; Curves *b* and *c*, defocused state in the horizontal and vertical directions, respectively. It can be seen from the figure that if the vertical and the horizontal defocusing are employed simultaneously the dark current pulse rate can be reduced by a factor 10. (Supply voltage —1000 V)

SECOND METHOD

The dark current pulse rate can also be reduced by deposit- g a conducting layer on the outer surface of the envelope the multiplier and connecting this layer to a potential near that of the cathode. This effect of shield potential has en referred to by Morton and Mitchell,(4) Rodda and eath(5) and de Valencé.(6)

In our investigations(7) the shield was an Aquadag layer posited on the outer surface of the envelope of the multi- ier. These investigations showed that the dark current ılse rate is mainly determined by the potential of the glass velope opposite the cathode, and that other parts of the Aqua- g layer were rather unimportant. If there is a high potential fference across the shield and photocathode the dark rrent pulses can be observed on the shield by suitable nplification. Thus it can be assumed that the essential part the dark current pulses arises from a current between e photocathode and that part of the envelope opposite it. is current generally produces pulses of high amplitudes.

This assumption is supported also by the fact that the shield tential has a greater effect on the dark current pulses of ge amplitudes than on those of small amplitudes. Fig. 4 ows the pulse height distributions with and without the quadag layer. The variation of the ratio of the Fig. 4 rves is shown in Fig. 5.

In interpreting the shield effect it should be noted that ere is a time lag between the variation of the shield potential d a variation in the dark current pulse rate. This seems indicate that the glass envelope also plays some part in e effect. In our experience the best way of ensuring the ıble operation of the multiplier is to maintain normal shield and cathode potentials (i.e. the shield potential is near to that of cathode). This method is justified by the fact that if the cathode and the shield potentials of the multiplier are switched off and on again, the dark current is greatly increased even if the multiplier is kept in darkness while the potential is switched off. The dark current pulse rate takes a considerable time to attain the value characteristic of the multiplier after the potential has been re-applied.

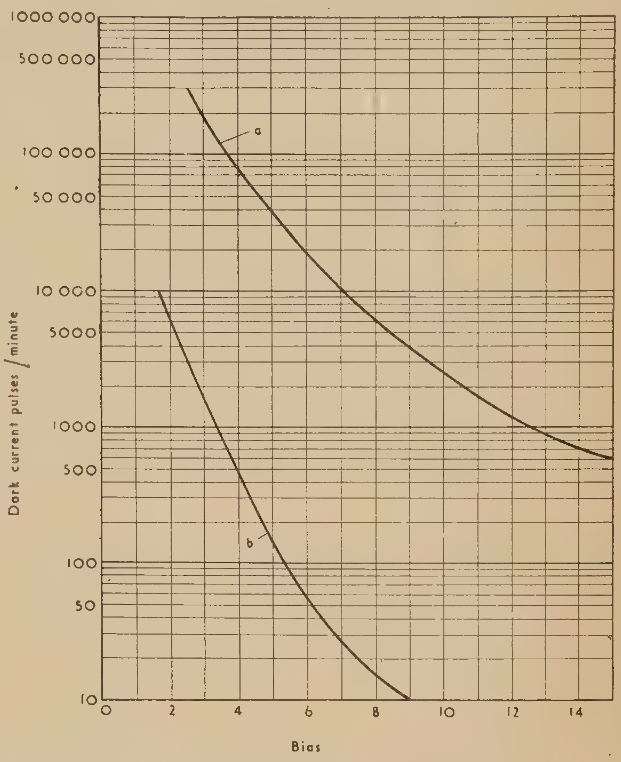


Fig. 4. Dark current pulse height distribution. Curve *a* no shield, Curve *b* normal shield potential. (Supply voltage —1080 V)

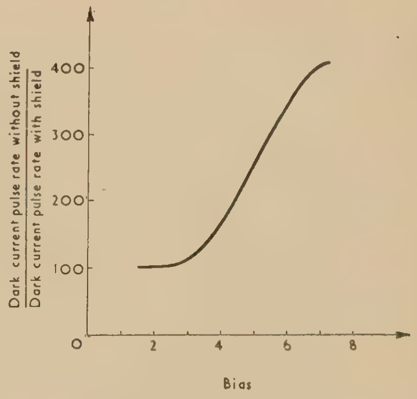


Fig. 5. The variation of the ratio of the Curves *a* and *b* shown in Fig. 4 with bias. It can be seen from the figure that the shield potential has a greater effect on the dark current pulses of large amplitudes than on those of small amplitudes

Our investigations have established that the multiplier gain is a function of the shield potential, i.e. if the shield attains a potential equal to or exceeding that of the cathode the gain increases by about 20% compared with its value at zero shield potential.

Since the dark current can be reduced by two orders of magnitude with the shield at normal potential we conclude that the dark current pulse rate of the multiplier at room temperature consists of two components:

(1) the dark current originating from the thermionic emission of the photocathode;
(2) the dark current which is affected by the shield potential.

Component (1) is smaller than component (2) by two orders of magnitude.

REFERENCES

(1) Engström, R. W. *J. Opt. Soc. Amer.*, **37**, p. 420 (19
(2) Bay, Z. *Z. Phys.*, **117**, p. 227 (1941).
(3) Zs. Náray. *Acta Phys. Hungar.*, **4**, p. 255 (1955); *M*
Fiz. F., **3**, p. 1 (1955) (in Hungarian).
(4) Morton, G. A., and Mitchell, J. A. *R.C.A. Rev.*
p. 632 (1948).
(5) Rodda, S., and Heath, F. G. Brit. Pat. Spec. 64576
(6) de Valencé, L. P. *Brit. J. Appl. Phys.*, **6**, p. 311 (19
(7) Zs. Náray. *Acta Phys. Hungar.* **5**, p. 159 (1955).

A Kösters-type interferometer

By C. F. Bruce, M.Sc., F.Inst.P., Division of Metrology, National Standards Laboratory, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia

[*Paper received* 7 *June*, 1956]

The design and performance are described of a Kösters-type interferometer which measures lengths of up to 500 mm directly by interferometry. Isotopic light sources are necessary for the measurement of the longer lengths, and sources containing mercury 198 and krypton 86, as well as natural krypton and cadmium, have been used with this interferometer. Results of some length and relative wavelength measurements are given, to illustrate the performance of the interferometer operating in air and *in vacuo*.

The Kösters interferometer(1) is a Michelson-type interferometer which is very useful for the measurement of end-standards of length. One of its main advantages is its use of a path difference which corresponds to the length of the standard and not to twice the length, as in Fizeau-type(2) and Fabry–Perot interferometers. It can therefore be used over a much larger range of lengths than is possible with these other types.

The construction of this interferometer was undertaken when no similar instrument was available. It has been used extensively in the high precision calibration of end-standards of this Laboratory and for international calibrations.

THE INTERFEROMETER

The instrument is shown in diagrammatic form in Fig. 1. The optical scheme of the instrument is the same in principle as that of the original Kösters interferometer, and includes an adjustable entrance aperture D_1, a collimating lens L_2, a dispersing prism P, beam-splitting and compensating plates A and A', a reference mirror M, a focusing lens L_3, an adjustable exit or viewing aperture D_2 and a Gauss eyepiece E for testing the optical alinement.

The source S is usually mounted in a box which can be adjusted vertically and horizontally. The lens L_1 is adjustable vertically and the aperture D_1 can be moved bodily in a horizontal direction. These adjustments provide adequate means of alinement. The aperture D_1 is a rectangular one formed by two pairs of adjustable jaws at right angles. The size of the aperture can be varied over a wide range by resetting, but it can also be varied continuously while in position by the use of knurled rings around the mounting of the aperture. The range of movement makes possible a change of about 0·3 mm in aperture width or length, and the aperture can be calibrated over this range. The lens L_2 is an achromatic doublet and the prism P a constant-deviation prism, made of three prisms of extra-dense flint. The beam-splitting and compensating plates A and A' are of high-quality optical glass, with wedge angles of several minutes to eliminate unwanted reflexions from the field of view. The dispersing prism P can be turned by using the drum C, which can be calibrated with a wavelength scale if necessary. The pri
can also be adjusted horizontally by means of spring-loa
adjusting pins which hold the prism between two cork-li
mounting plates. The plates A and A' can be adjuste
level by three screws. The mirror M is a high-quality surf
mirror, the position of which can be changed by means o
chain drive operated by the hand wheel Q. The mirro
roller-mounted on two guide rods F with a friction b
which operates when the hand wheel Q is not being mov
The mirror can also be adjusted for tilt by three support
screws in its mounting.

The gauge G with its platen B rests on the base plate
which may be raised or lowered by the remote control ha
drives N and K. These motions are obtained through
worm wheel which, acting directly on an elevating scre
moves the lower plate on which the base plate R is mount
Fine motion is obtained with the drive K and operates direc
through the worm wheel. Coarse motion is obtained w
the drive N and operates through a system of gears. Th
are two hand drives H for tilting the base plate, while J i
locking device on the traverse motion. The focusing lens
is a good achromat, and aperture D_2 is similar to D_1 exce
that it may be adjusted vertically as well as horizonta
relative to the optical axis. The focal lengths of the co
mating and focusing lens are about 208 and 390 m
respectively, and the effective aperture of the instrument
about 65 mm. The whole interferometer is about 4½ ft. lo
4½ ft. high and is mounted on a concrete pillar about 1½
square and 2 ft. high.

The main difference from the original Kösters interfer
meter is the use of an adjustable mirror M instead of a fix
one. This enables any length or path difference from ze
to 500 mm to be used with ease without any motion of t
whole of the optical head on a column. As a result a ve
robust instrument was designed, in which remote controls f
the movement of the reference mirror and the gauge we
readily incorporated, and in which provision was made f
measurements at controlled temperatures and *in vacuo*.

The gauge may be placed in the main interferomet
chamber for measurement in air at ambient temperatures,
it can be placed in a vacuum jacket around which water

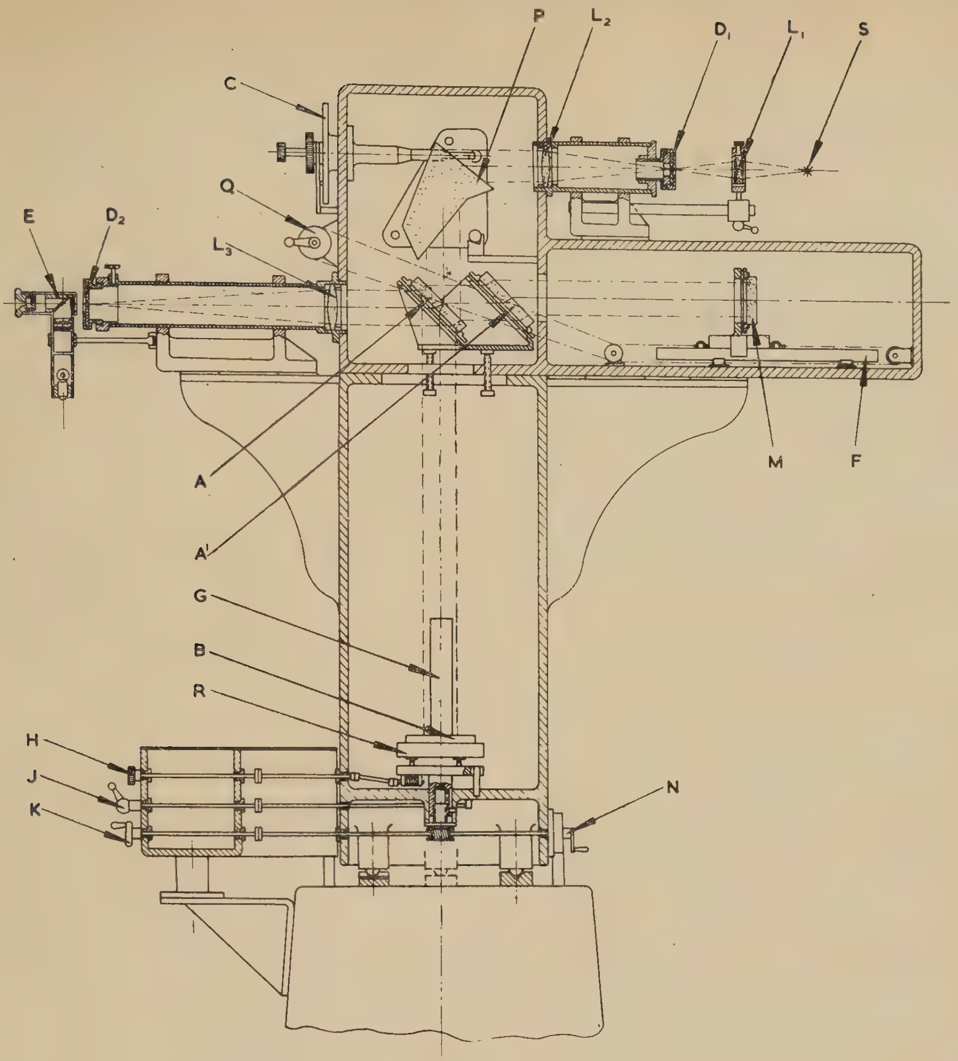


Fig. 1. Optical scheme for Kösters–N.S.L. interferometer

ontrolled temperature circulates in the annular chamber etween the inside and outside of the jacket.

Fig. 2 shows a general view of the instrument, together vith some of the apparatus for the control and measurement f temperatures, for the evacuation of the jacket, and for the peration of the light source, which is mounted in a wooden ox. Fig. 3 shows an end standard in position for measurement in air without precise temperature control. The platen o which the standard is wrung rests on the base plate which n turn is mounted on a lower plate. The tilting controls for he lower plate are seen in the photograph. The traversing ontrols are below the floor of the chamber.

Fig. 4 shows the vacuum jacket ready for sliding into osition for measurements *in vacuo*. This jacket is used for oth air and vacuum determinations when precise temperature ontrol is required. The platen and gauge are lowered into he jacket in a long metal cradle. At the bottom of the acket the platen rests on a solid platform, leaving the cradle ut of contact with the platen. The jacket can then be sealed nd moved into position on a platform which slides on uiding rails. The lower plate can be elevated until the acket is resting on this plate. The platform can then be emoved and the guide rails swung up to the position seen n Fig. 3. It is intended to replace this vacuum jacket by a new design which allows the gauge and platen to be placed in the jacket by hand, and which in general allows free access to the inside of the jacket by opening a vacuum-tight door. Water circulation around the jacket will still be provided.

All measurements are carried out in an air-conditioned room in a basement in which the temperature is controlled within ±0·5° C of 20° C. The connexions for water circulation, evacuation and temperature measurement lead from the back of the chamber in which the jacket is placed.

TEMPERATURE AND VACUUM EQUIPMENT

The temperature of the water circulating in the vacuum jacket is controlled by means of a sensitive resistance thermometer element placed in a tank from which water is pumped through the vacuum jacket. The tank contains heating and cooling coils which provide effective control, and the water is stirred continuously.

The temperature-sensitive element consists of a winding of fine copper wire on a copper form, and is part of a Wheatstone bridge network. The out-of-balance voltage which results from changes in the temperature of the water surrounding the sensitive element, is fed into a high-gain amplifier, from which a voltage is applied to the heaters in the control tank. This type of proportioning controller was developed by Wylie,(3) and the electronic controller unit used at this Laboratory was designed by Ross and Gore.(4) The bridge can be set to control at any temperature in the range 10 to 30° C. Initially the moving water caused vibration in the interferometer, so the water was continuously pumped up to a small glass tower from which it flowed away under the steady action of gravity. This entirely removed trouble from vibration.

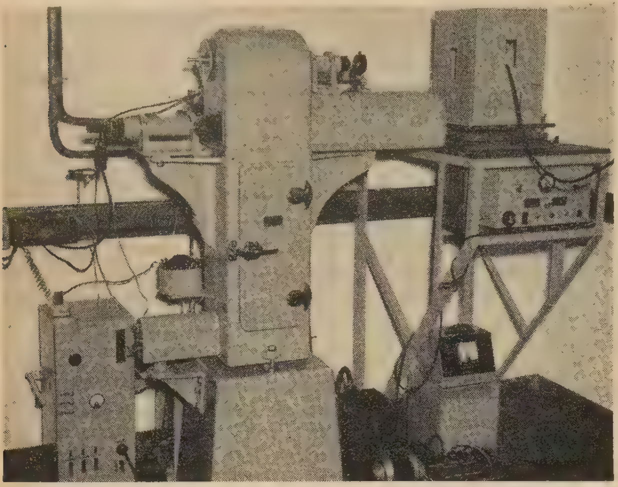


Fig. 2. The Kösters–N.S.L. interferometer

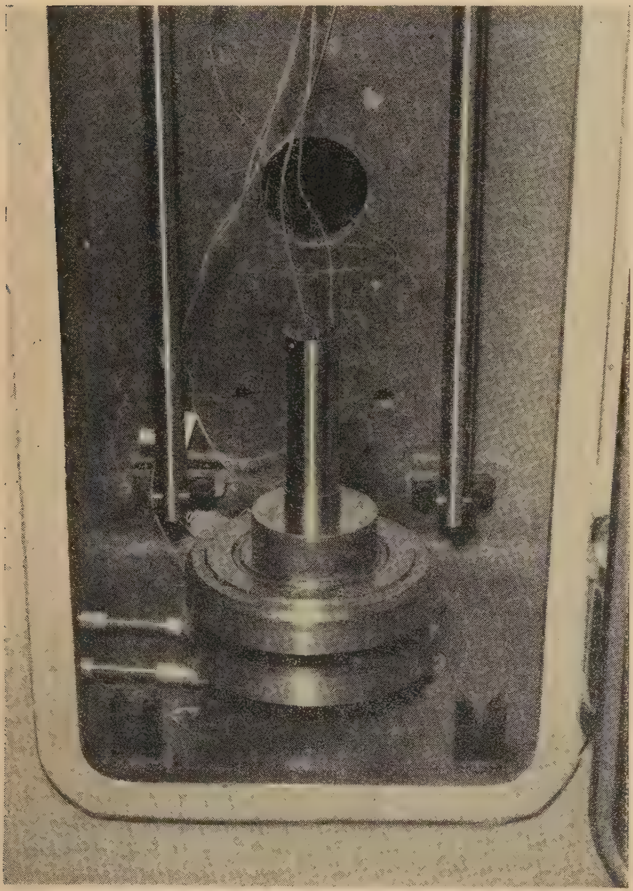


Fig. 3. End standard in interferometer chamber ready for measurement in ambient air

In the measurements described in this paper a small jac containing a standard thermometer immersed in oil w included in the water circulating circuit for measureme with precise temperature control. To this thermometer reference junctions of a series of calibrated copper-constan thermocouples were attached. The other junctions w attached to the gauge, or other points in the interferome chamber or vacuum jacket, the temperatures of which w required.

Provision is made for measuring the thermal e.m.f. means of a sensitive galvanometer which is calibrated, o thermoelectric free Diesselhorst potentiometer. For ve high sensitivity the thermal e.m.f. can be fed into a galvan meter amplifier, the output of which is measured with calibrated galvanometer. These facilities provide means measuring temperature differences over a large range with reliability of 0·001° C. For the highest precision in absolu values of temperature the standard mercury-in-glass therm meter may be replaced by a platinum resistance thermomete the resistance of which is measured on a Mueller bridge. the measurements described here a standard mercury-in-gla thermometer, calibrated with an accuracy of ±0·005° was used. Temperature differences were measured by dire galvanometer deflexion, where a scale deflexion of 1 m corresponded to 0·003° C.

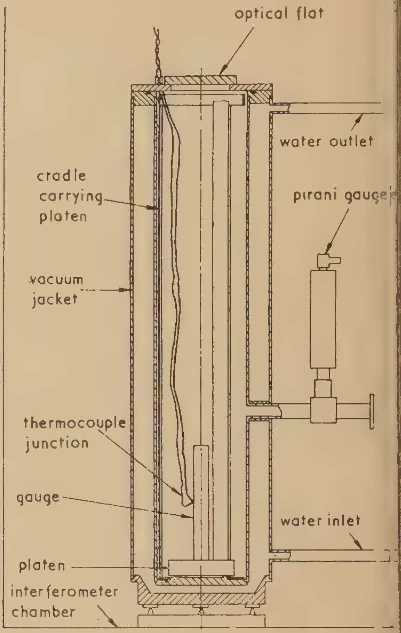


Fig. 4. Vacuum jacket used for measuring lengths *in vacuo* or in air under controlled temperature conditions

For air measurements at ambient temperatures the referen thermometer was placed in a Thermos flask containing o If several hours were allowed for temperature stability to b established, the difference between the gauge temperatu and the standard thermometer temperature seldom exceede 0·05° C, whether the measurements were at ambient temper tures or under conditions of precise temperature control.

The temperature control system operated very satisfactori for measurements in air and vacuum. Over the period several minutes required for a set of observations of th fringe fractions, the temperature stability of the air and gaug in the vacuum jacket and of the reference thermometer wa of the order of 0·001° C. For periods of several hours, th drift in temperature was rarely more than a few hundredth of a degree centigrade. Fig. 5 illustrates a typical performanc f the temperature control system, during which temperatures vere taken at intervals of 5 min over 3½ h. The full and lotted curves show respectively the temperatures of the top nd bottom of a 100 mm gauge. The separation of the two urves initially indicates a small temperature gradient in the auge which finally decreases to a negligible amount.

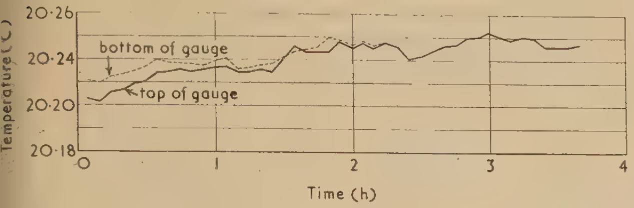


Fig. 5. Temperature control of gauge in vacuum jacket of interferometer

The vacuum jacket was evacuated with a Cenco-Megavoc otary pump (by the Central Scientific Co., Chicago) to ressures below 0·03 mm of mercury. The thermocouple eads were taken through polyvinyl chloride plastic moulded round the wires. These plastic moulds passed through oles in the jacket lid. The vacuum seal was completed by pplying glyptal. An optical flat with an O-ring seal on the op of the jacket lid allowed light to enter from the optical ystem. The flat had a wedge angle of several minutes and vas orientated to eliminate ghost reflexions from the field of iew. The pressure was measured with a Pirani gauge fitted o the exhaust outlet of the jacket.

THE LIGHT SOURCES

The performance of the interferometer was tested for path lifferences of up to 500 mm by using a range of light sources, he visible wavelengths from which are suitable as standards f length. In particular the performance of a range of sotopic light sources was studied. Krypton 86 isotope lamps ave been made available to this Laboratory by the hysikalisch-Technische-Bundesanstalt (P.T.B.), West Gernany, and mercury 198 lamps by the National Bureau of tandards (N.B.S.), U.S.A., and the National Research Council (N.R.C.), Canada. Mercury 198 lamps were also btained from the General Electric Co. Research Laboratories G.E.C.), England.

Table 1. *Wavelengths for standard air*

dry air at 15° C, 760 mm of mercury, and containing 0·03% carbon dioxide by volume)

Radiation		*Wavelength (Å)*
Cadmium	red	6438·4696
	green	5085·8212
	blue-violet	4799·9104
	violet	4678·1493
Mercury 198	yellow 1	5790·6628
	yellow 2	5769·5984
	green	5460·7532
	violet	4358·3376
Krypton	red	6456·2910
	orange-red	6056·1274
	orange-yellow	5993·8513
	yellow	5870·9169
	yellow-green	5649·5628
	green	5570·2903
	violet	4502·3550

The cooling of the electrodeless mercury 198 lamp was done by placing it in a water jacket so that cold tap water passed continuously around it. For lengths up to 8 in. the krypton lamps were operated in air. Above 8 in. they were cooled by immersion in liquid air or oxygen. In the case of the krypton 86 lamp, cooling below 60° K (−213° C) was achieved by evaporating off liquid nitrogen and oxygen with a high-speed rotary vacuum pump. An oxygen thermometer was used to measure the low temperature. The wavelengths used in the direct determinations of length are given in Table 1.

The cadmium values are those obtained by Sears and Barrell.(5) The mercury 198 values are the mean of results obtained by Meggers,(6) Barrell and Puttock,(7) Pérard and Terrien,(8) Meggers and Westfall,(9) Blank(10) and Meggers and Kessler.(11) The krypton values are derived from the vacuum results of Littlefield(12, 13) using the Barrell and Sears(14) dispersion equation.

OBSERVATIONS AND CORRECTIONS

Details of temperature and vacuum equipment have already been described. The fringe fractions for the wavelengths from each light source were observed and repeated in reverse order before changing to another light source. Readings of temperature, pressure and humidity were taken before and after each set of observations. The pressure was measured with a Fortin barometer to the nearest 0·05 mm of mercury, and the vapour pressure was measured with a psychrometer.

The significance of the fractional displacements observed between the fringes on the gauge and those on the platen to which the gauge is wrung is well known and is described by Barrell.(2) The modified Benoît(15) method of exact fractions or coincidences as devised by Kösters(1) was used to determine the departures from nominal size for each length.

Corrections for the refraction and dispersion of air were obtained by using the dispersion equation of Barrell.(16) The coefficient of linear expansion of each gauge was determined initially over the temperature range 19·5 to 20·5° C using the interferometer. Appropriate corrections were applied to obtain lengths at 20° C.

Obliquity effects arising from the finite size of the diaphragm apertures D_1 and D_2 (Fig. 1) have been analysed in detail by Bruce(17) and Thornton.(18) In these measurements the entrance aperture controlled collimation, and its size was 0·08 × 0·3 mm. The focal length of the collimating lens was 208 mm. This case is sufficiently close to that of the narrow slit in which the maximum obliquity angle θ is $7{\cdot}21 \times 10^{-4}$ radian. The appropriate correction for a given length t and a given wavelength λ can be obtained from curves.(19)

The application of the method of coincidences and of the corrections for refraction and dispersion were obtained readily with the aid of suitably designed tables.(20)

The mercury 198 green line from the N.B.S. electrodeless lamp was selected as a reference line because of its brilliance and the ease with which it could be used over large path differences. For these comparative measurements, the wavelength of this line for standard air was accepted as 5460·7532 Å. This is the certified value quoted by the National Bureau of Standards for this particular lamp.

RESULTS

Important use was made of the instrument in an international calibration of end standards of length supplied to this Laboratory (N.S.L.) by the Bureau International des Poids et Mesures (B.I.P.M.). These standards were of rectangular section and of very high quality for flatness, parallelism and surface finish. Mercury 198 wavelengths were used and fringe fractions were estimated visually. This work was part of a programme organized by the B.I.P.M. The results for the practical length (the geometrical length plus any contact error introduced by wringing) are given in Table 2.

Table 2. *Comparative length measurements of end standards*

Nominal size (mm)	*Departures from nominal size at 20° C (μ)*				
	N.S.L.		*B.I.P.M.*	*N.S.L.*	
	Oct. 1953	*Oct.* 1955*	*Feb.* 1954	*June* 1954	*Oct.* 1955*
25	+0·039	+0·041	+0·041	+0·036	+0·038
50	+0·082	+0·086	+0·073	+0·061	+0·065
75	+0·110	+0·114	+0·112	+0·111	+0·115
100	+0·149	+0·155	+0·159	+0·152	+0·158

* These results were obtained by applying a small obliquity correction to the results obtained in October 1953 and June 1954. This correction is the mean of the corrections at $\lambda = 4000$ Å and at $\lambda = 6000$ Å. The difference between this mean and the individual corrections is 0·002 μ for the 100 mm length, and is still less for the other lengths. The maximum difference between the results obtained by the B.I.P.M. and the N.S.L. is 0·013 μ, and most of the values are well within 0·01 μ. Comparing the N.S.L. October 1955 values for the four lengths with the B.I.P.M. values, the mean difference is within 0·005 μ.

Table 3 gives the results of a series of length measurements in air for sizes ranging from 1 to 20 in. in which seven different light sources were used. End gauges of commercial quality were used and fringe fractions were estimated visually with an accuracy of 0·05 fringe to 0·1 fringe. Small errors in flatness and parallelism of the end faces of some of the gauges limited the accuracy of the results for some lengths. Considering these facts, the agreement between all lamps for lengths up to 10 in. is satisfactory. The agreement between mercury 198 lamps and the cadmium lamp is generally very good. The results for the krypton isotope lamp were obtained using wavelength values of natural krypton given in Table 2. The generally higher results for the lengths above 10 in., when the lamp was operating at 60° K, indicate that the wavelengths are smaller than those for natural krypton.

Table 3. *Comparative length measurements in air relative to lamp* (1)

Departures from nominal size in 10^{-6} *in.*

	Lamps						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Nominal	*Electrodeless type*			*Cold cathode*	*Hot cathode type*		
size (in.)	^{198}*Hg* *N.B.S.*	^{198}*Hg* *N.R.C.*	^{198}*Hg* *G.E.C.*	^{198}*Hg* *G.E.C.*	*Kr* *G.E.C.*	^{86}*Kr* *P.T.B.*	*Cd* *G.E.C.*
1	0	+0·1	−0·2	+0·5	−0·1	+0·1	−0·3
2	0	−0·8	−0·4	−0·9	−0·7	0·0	−0·4
3	0	+0·7	−0·4	+0·5	+1·3	+1·0	−0·4
4	0	−0·6	+0·6	+0·3	+0·4	+1·2	−0·8
5	0	−0·3	−1·1	+0·4	+2·8	+2·4	+0·7
6	0	+0·6	+0·9	+0·5	+1·8	+2·4	−0·5
7	0	−0·1	−0·2	−1·6	+1·0	+2·1	−4·0
8	0	−0·2	−1·3	—	+3·4	+3·5	−2·5
10	0	+0·1	+0·6	—	+2·8	+3·8	—
12	0	+1·5	+0·2	—	+2·2	+6·2	—
14	0	+0·1	−2·5	—	—	+5·6	—
16	0	0·0	+0·5	—	—	+6·8	—

The performance of the interferometer under vacuum conditions is illustrated by some relative wavelength values determined from measurements in air and *in vacuo*, and these are given in Table 4. The measurements were made using the green line of mercury 198 from the N.B.S. lamp a standard ($\lambda = 5460 \cdot 7532$ Å).

Table 4. *Wavelength values for standard air*

Lamp	*Measurement in*	*Wavelengths (Å)*	
^{198}Hg N.B.S.	air	5790·6632	4358·33
electrodeless	vacuum	5790·6625	4358·33
Kr G.E.C.	air	6456·2911	4502·3
hot cathode	vacuum	6456·2905	4502·3
^{86}Kr P.T.B.	air	6456·2914	4502·3
hot cathode	vacuum	6456·2913	4502·3
Cd G.E.C.	air	6438·4707	4678·1
"Osira" lamp	vacuum	6438·4709	4678·1

It is emphasized that these values are not presented precise results but as an indication of instrument performar under vacuum conditions as compared with measurements air. The conditions of measurement prevent fringe fractio from being measured to better than 0·05 fringe whi corresponds, for example, to an accuracy of 1 in 10^7 5000 Å for a 5 in. length. Precise measurement of wa lengths, by other methods, is in progress.

ACKNOWLEDGEMENTS

The Drawing Office and Workshop of the Nation Standards Laboratory were responsible for the detail mechanical design and construction of the instrument. M N. A. Esserman, Dr. H. J. Ritter, and Mr. R. H. Furn assisted in the final design of the instrument, and expe mental assistance was given by Mr. W. A. F. Cuninghar and Mr. J. R. Cleary.

REFERENCES

(1) Kösters, W. *Z. Feinmech*, **34**, p. 55 (1926).
(2) Barrell, H. *Research*, **1**, p. 532 (1948).
(3) Wylie, R. G. *C.S.I.R.O. Aust. Div. Phys.* Rep. P.A (1948).
(4) Ross, H. A., and Gore, G. W. *N.S.L. Tech. Pape* No. 2 (C.S.I.R.O., 1955).
(5) Sears, J. E., and Barrell, H. *Proc. Roy. Soc.* **139**, p. 202 (1933).
(6) Meggers, W. F. *C.R.* 9° *Conférence Générale des Poi et Mesures*, p. 75 (Paris: Gauthier-Villars, 1948).
(7) Barrell, H., and Puttock, M. J. *C.R.* 9° *Conféren Générale des Poids et Mesures*, p. 75 (Paris: Gauthie Villars, 1948).
(8) Pérard, A., and Terrien, J. *C.R. Acad. Sci.* [*Paris* **228**, p. 964 (1949).
(9) Meggers, W. F., and Westfall, F. O. *J. Res. Na Bur. Stand.*, **44**, p. 447 (1950).
(10) Blank, J. M. *J. Opt. Soc. Amer.*, **40**, p. 345 (1950).
(11) Meggers, W. F., and Kessler, K. G. *J. Opt. So Amer.*, **40**, p. 737 (1950).
(12) Littlefield, T. A. *Proc. Roy. Soc. A*, **187**, p. 220 (1946
(13) Littlefield, T. A. *Nature* [*London*], **165**, p. 187 (1950
(14) Barrell, H., and Sears, J. E. *Phil. Trans A*, **238**, p. (1939).
(15) Benoit, R. *J. Phys.*, **7**, p. 57 (1898).
(16) Barrell, H. *J. Opt. Soc. Amer.*, **40**, p. 395 (1951).
(17) Bruce, C. F. *Austral. J. Phys.*, **8**, p. 224 (1955).
(18) Thornton, B. S. *Austral. J. Phys.*, **8**, p. 241 (1955).
(19) Bruce, C. F. *J. Opt. Soc. Amer.*, **45**, p. 1084 (1955).
(20) Bruce, C. F. *N.S.L. Tech. Paper* No. 8 (C.S.I.R.O 1955).

A simple direction-sensitive phototransistor circuit for use in optical pulse-counting systems*

By W. T. BANE, B.Sc., and D. L. A. BARBER, B.Sc., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 10 *August*, 1956]

A current technique for measuring digitally the angular position of a shaft involves counting pulses generated by the interruption of a beam of light falling on two photocells by a serrated disk mounted on the shaft.

A very simple phototransistor circuit is described which detects the passage of a serration and provides an output pulse on one of two lines, according to the direction of rotation, so that an electronic counter can be made to change its count accordingly. The circuit can be used with other, similar techniques for linear measurement and may be modified for counting interference fringes or moiré fringes.

1. INTRODUCTION

n recent years it has become necessary to develop techniques for measuring digitally the positions of mechanical members, and methods of doing so have been devised for the angular displacements of rotating shafts and the linear displacements of members such as carriages running on slides. Of the various techniques, one with several attractive features is that n which position is determined by sensing optically and counting the passage past a fixed point of a succession of shadows, interference or moiré fringes produced by motion of the member.

A simple system of this type for determining shaft position s shown in Fig. 1. A serrated disk mounted on a shaft is used to interrupt a beam of light falling on a pair of photocells mounted side by side. The outputs from the photocells are used as the input to a counter in such a way that each time the beam is interrupted a count is added or subtracted according to the direction of rotation: to determine direction of rotation, two photocells are necessary.

The attractions of this scheme are that no constraint is put upon the shaft and that, provided fine measurement is not required, the actual measuring head can be very simple. In addition, the problem of transmitting the data is merely that of transmitting signals corresponding to "add one" and "subtract one," and to alter the zero of measurement only entails setting the counter to zero at the appropriate shaft position.

On the debit side, there is the fact that the output of the measuring head has to be integrated in a counter, with the result that if a count is missed or if the power fails, the zero is permanently shifted. However, a commercially available equipment using this type of system has been operated successfully and reliably for several years. In any case, it is possible to conceive of more complicated systems in which additional marks disposed throughout the working range check and re-set the reading of the counter.

The circuit that will be described performs the basic function of generating a pulse each time a shadow is sensed and also that of indicating direction of motion. The output pulses appear on one of two lines according to whether the count has to be added or subtracted. The circuit is very simple and is small enough to be mounted as part of a measuring head; it employs two phototransistors and two further transistors which act in part as output buffer amplifiers. It has the further advantage of being largely independent of the waveform of the light signal.

The circuit will be described in terms of the simple system of Fig. 1 for which it was originally devised. By modifying the optical and mechanical arrangements, it can be used for much finer angular measurement and for the measurement of linear displacements. It may also be made in a form suitable for electrical inputs such as amplified photocell signals, and thus may be used with very low illuminations and can be applied to the counting of interference fringes or moiré fringes.

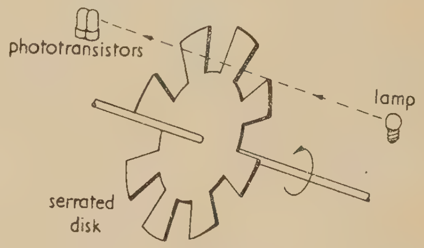


Fig. 1. Physical arrangement of a simple circuit

2. REQUIREMENTS FOR THE CIRCUIT

Before proceeding to a description of the circuit, it is desirable to consider the operational requirements in more detail. At first sight, it would seem reasonable to make the system so that a count is registered when a serration passes through a particular position relative to the photocells, the direction of passage of the serration indicating whether the count is positive or negative. There is, however, a danger inherent in such a system: if the disk is stationary or moving slowly in a position close to that where a count is registered, vibrations or circuit noise may produce—or try to produce—a rapid train of alternate positive and negative counts and some may be missed. It is desirable, therefore, to arrange the circuit so that a finite movement of the disk is necessary before a positive count can follow a negative one or *vice versa*; there must be a "backlash" effect. There is also the obvious requirement that the circuit must work down to zero frequency and up to a frequency appropriate to the application.

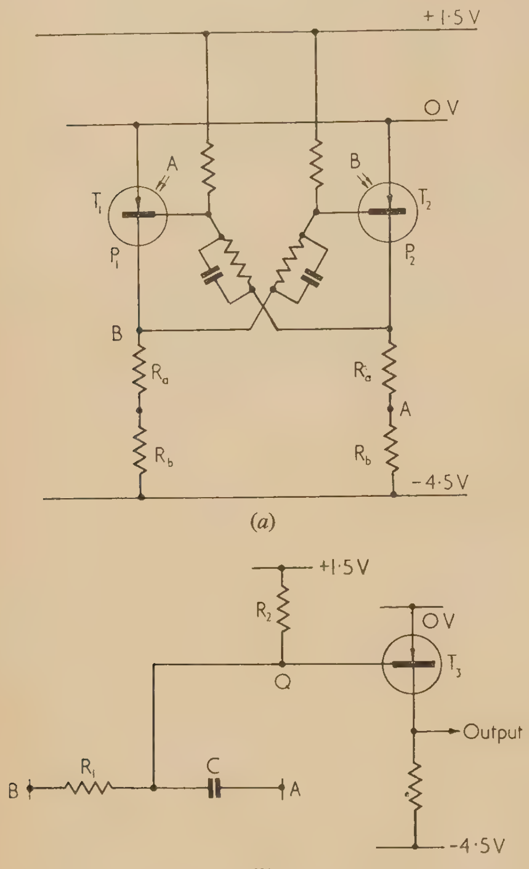
3. BASIC CIRCUIT

One possible form of the basic circuit is shown in Fig. 2(*a*). It consists of two phototransistors connected in the form of the well-known Eccles–Jordan trigger circuit. Under normal conditions this circuit has two stable states; transistor T_1 will be conducting with transistor T_2 cut off or *vice versa*.

A phototransistor, while it will act as a normal transistor, can be made to conduct by incident light, even though it is "cut off" by the base being taken positive with respect to the emitter. In effect, the light may be regarded as an additional negative signal added into the base of a normal transistor. Thus the circuit of Fig. 2(*a*) can be triggered from one stable state to the other by shining light on to the appropriate phototransistor. In addition, if sufficient light is shone on to both transistors, both can be made to conduct so that the circuit is forced into a normally unstable condition.

---

* British Patent Application No. 15071/56.



(*a*)

(*b*)

Fig. 2. (*a*) Basic trigger circuit. (*b*) Detecting circuit for one direction of rotation

The operation of the circuit can best be understood by referring to Fig. 3(*a*) which shows diagrammatically how the two light signals change when a mark is moved past the photocells. Here, one complete count-cycle is represented by a complete traverse of the circle by the reference point *X*, the direction of rotation of the point corresponding to the direction of rotation of the shaft. The sectors marked *A* and *B* correspond to the illumination of the transistors by the two light signals. It should be noted that this diagram only represents the states of the two light signals and should not be considered as a physical representation of the system shown in Fig. 1. If the point *X* is traversed around the circle in a clockwise direction from the position shown, the following actions take place, it being assumed that there is sufficient illumination to cause both transistors to saturate when they are both illuminated:

(*a*) initially, only signal *B* is present so that T_2 conducts and T_1 is turned off;

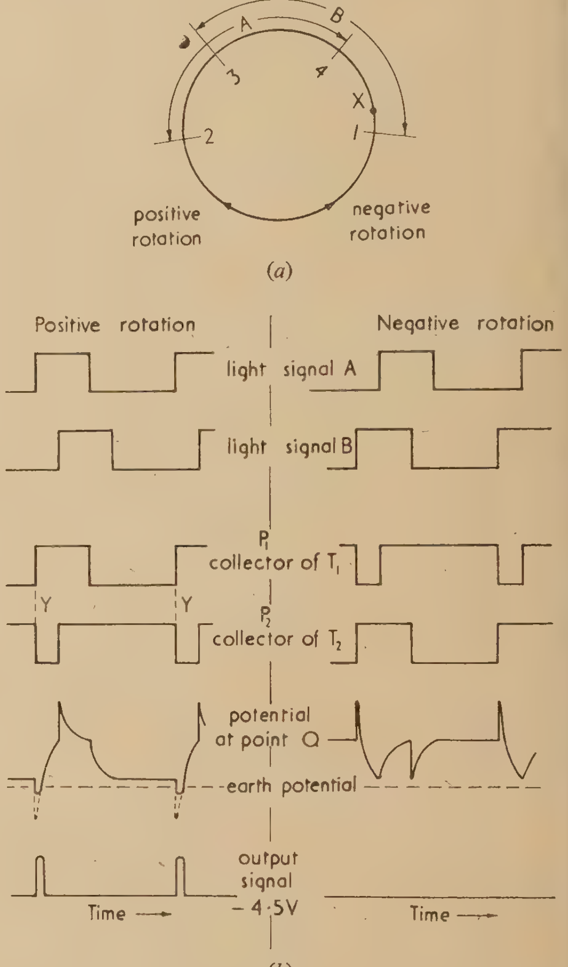
(*b*) at point 1, signal *B* is removed but no change occurs in the circuit as signal *A* is still absent;

(*c*) at point 2, signal *A* comes into being with the result that the circuit triggers to the opposite state. T_1 n conducts and T_2 is cut off;

(*d*) at point 3, signal *B* is reinstated causing T_2 to cond T_1, however, remains conducting as signal *A* is s present;

(*e*) at point 4, signal *A* is removed so that T_1 is cut leaving T_2 still conducting.

Note that the change of state at point 2 is unique in so as it is the only one in which both transistors change th state. In addition, it is the only change where the circ triggers and where its action is therefore independent of t light signals, apart from *A* crossing a threshold. The char of state at point 2 is taken as indicating a positive count.



(*a*)

(*b*)

Fig. 3. (*a*) Sequence diagram. (*b*) Idealized waveforms

For negative rotation, a basically similar sequence carried out. Here, however, the circuit triggers from on state to the other at point 1. Also, it triggers in the opposit direction; T_1 is turned off and T_2 on. Thus a positive coun may be registered when T_1 is turned on simultaneously wit T_2 being turned off, and a negative count registered for th opposite behaviour.

Fig. 3(*b*) is an idealized diagram of the light signals *A* an *B*, and the corresponding voltage signals at various points i the circuit for each direction of rotation.

Referring again to Fig. 3(*a*), now suppose that the reference oint X first rotates in a positive direction until it is just past oint 1. Over the sector 1 to 2, T_2 will be on and T_1 off. At oint 2 the states will reverse and a positive count will be egistered. If the direction of rotation is now reversed, there vill be no change as point X re-traverses point 2 in the pposite direction; T_1 will remain on and T_2 off. The states vill, however, reverse at point 1 where a negative count will e registered. Thus the reference point must move through he sector 2 to 1 before a negative count can be made to follow positive one and the same condition holds for the reverse otation. This gives the necessary "backlash" which can be aried by altering the extent of the sector where neither hototransistor is illuminated, i.e. sector 1 to 2.

Section 4 describes a circuit for detecting the two operative hanges of state.

4. DETECTING CIRCUIT

The detecting circuit is illustrated in Fig. 2(*b*) where, for larity, the circuit for positive rotation only is shown, ivorced from the basic circuit.

Transistor T_3 is normally held cut off and, under these onditions the charging and discharging time-constant of ondenser C is determined mainly by C, R_1 and R_2 as the esistors are large compared with the collector load resistors. t is chosen to be small compared with the shortest possible nterval between changes of state, this being determined by he maximum speed of rotation of the shaft.

Resistors R_a and R_b [see Fig. 2(*a*)] are arranged so that he voltage swing of point B due to transistor T_1 being turned n and off equals that at point Q due to transistor T_2 being urned on and off. Under these conditions, the potential waveforms at point Q are as shown in Fig. 3(*b*). It can be een that the base potential of transistor T_3 falls below earth ausing the transistor to conduct only at the points marked Y in the figures. These are the points corresponding to positive counts (see Section 3). The dotted amendments to the waveforms illustrate the potentials which would apply at point Q if the base of T_3 were disconnected. The waveforms shown in Fig. 3(*b*) have been idealized for clarity; in practice they will be slightly altered, but the operation of the circuit remains unchanged.

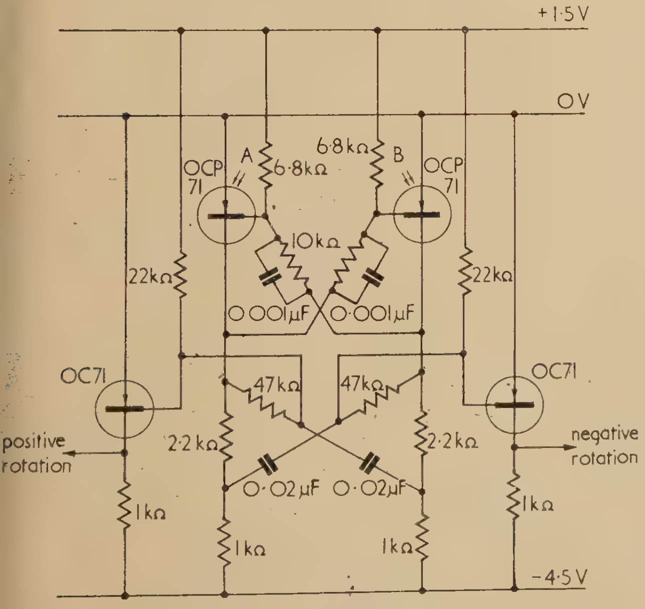


Fig. 4. Complete circuit

A similar circuit is used for detecting negative counts and the complete circuit diagram is shown in Fig. 4.

5. PRACTICAL ARRANGEMENT

The circuit has been constructed in the form of a plug-in printed circuit and a composite photograph of it showing both sides of the card together with the serrated disk for which it was designed is shown in Fig. 5. The circuit card is about 4 in. square and the disk about $2\frac{1}{2}$ in. in diameter. The photocells are positioned on the card by a clip and a miniature 1 W lamp mounted on the reverse side illuminates them through holes in the card. The disk has ten slots, and is mounted so that it rotates between the card and the lamp; a lens system is not necessary.

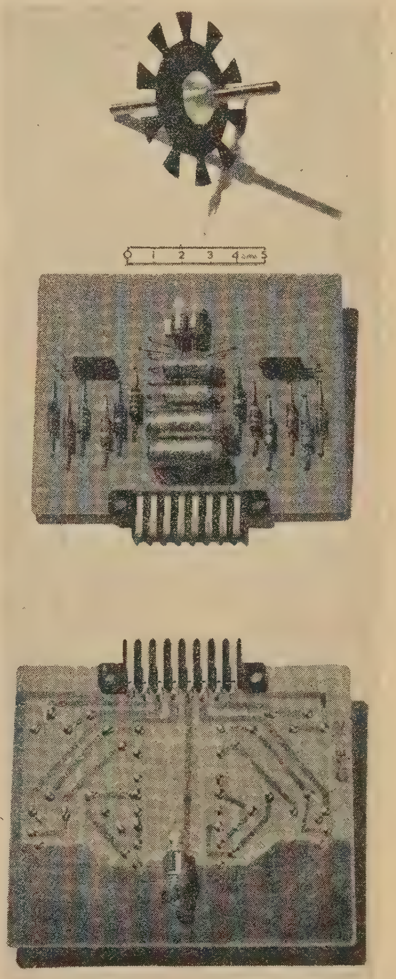


Fig. 5. Practical arrangement

6. CONCLUSIONS

The circuit that has been described is simple, small and cheap. Although it has been described as being used with a coarsely divided rotating disk it can, by altering the mechanical and optical arrangements, be used for much finer measurements and in measuring linear displacements.

It has also been described in a particular form suitable for illumination signals, but the basic trigger and detecting circuits can be modified as thermionic valve circuits and can also be modified for electrical inputs. It is therefore suitable for use with amplified photocell signals for applications where there is insufficient light to operate the phototransistor circuit directly; in this form it may be used for counting interference fringes or moiré fringes.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the suggestions and h received from their colleagues in the Division, in particu from Mr. M. P. Atkinson.

The work described above has been carried out as part the research programme of the National Physical Laborato and is published by permission of the Director of Laboratory.

A simple method for the measurement of high resistance values

By A. E. Hawkins, B.Sc., A.R.C.S., A.Inst.P., Department of Physiology, Royal Veterinary College, University of London

[*Paper received* 3 *July*, 1956]

A modified Wheatstone network is described for the measurement of resistance values up to 10^9 Ω. The accuracy is better than ±2%.

Price* outlines a procedure whereby a Wheatstone network may be used to measure high resistance values. Any small, out-of-balance potential difference instead of being applied across a galvanometer is allowed to charge a high capacitance condenser and the energy stored in the condenser is discharged through a galvanometer. If the condenser is given sufficient time to charge completely, then the sensitivity of the apparatus is independent of the values of the resistances comprising the network.

In this simple form the network was found difficult and tedious to use. Complete charging had to be permitted to obtain an accurate balance. This made each determination very slow indeed. When incomplete charging was attempted, slight variations in the charging period caused incorrect adjustments to be made to the network. This, again, slowed up each determination and the difficulty in obtaining balance produced results with a 5% scatter.

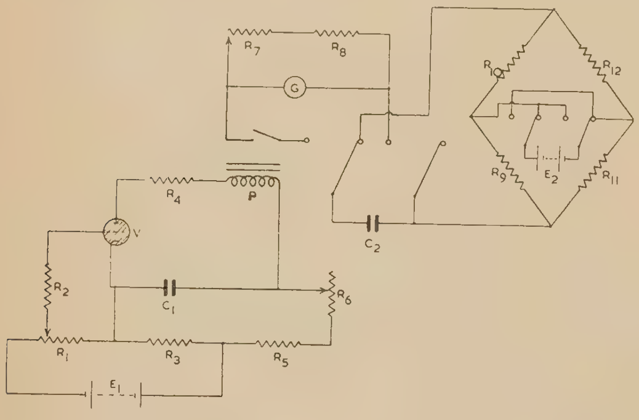


Fig. 1. Circuit diagram of the modified Wheatstone network

R_1 = 15 kΩ
R_2 = 47 kΩ
R_3 = 285 kΩ
R_4 = 500 Ω
R_5 = 470 kΩ
R_6 = 2 MΩ
R_7 = 100 kΩ
R_8 = 100 Ω
R_9 = unknown
R_{10} = 3 MΩ
R_{11} = 100 kΩ decade
R_{12} = 10 kΩ decade
C_1 = 2 μF
C_2 = 2 μF
V = GTIC
G = Sullivan portable galvanometer, 460 Ω, 2480 mm/μA
P = Siemens relay type 100, 100 Ω
E_1 = 120 V dry battery
E_2 = 45 V dry battery

Automatic switching at regular intervals made the arrangement almost as quick and easy to use as a normal network. The circuit used for testing the method is shown in Fig. 1. The switching is carried out by a simple thyratron relaxation oscillator driving a double changeover relay. The dou changeover is necessary to avoid confusion arising near t balance position due to a slight drift of the galvanomet spot when one side of the galvanometer is left connected one side of the condenser.

To protect the galvanometer, a rough balance is obtain with 100 Ω across the galvanometer and a charging time 3 s. The charging time and the value of the shunt are increas by adjusting R_6 and R_7 respectively and the bridge broug into more accurate balance. The key is kept closed durin the final stages.

It was not found necessary to increase the charging ti beyond 10 s with a battery electromotive force of 45 when measuring resistance values up to the order of 10 despite the fact that complete charging did not occur. was found essential to determine the ratios for the tw current directions because of thermoelectric effects.

The values of some Welmeg, glass enclosed, high val resistors (by Welwyn Electrical Laboratories Ltd.) singly, parallel and in series were determined with the circu described. The values were determined by leakage ar also by a constant galvanometer deflexion method using Rayleigh potentiometer. The circuit for the latter metho is shown in Fig. 2. The values of the resistance boxes

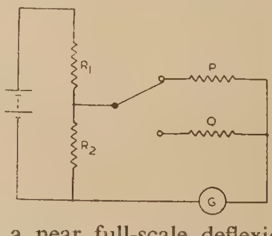


Fig. 2. Circuit diagram of the potentiometer method of measuring resistance

P = 5 MΩ
R_1, R_2 = 10 kΩ decade

and R_2 are adjusted for a near full-scale deflexion of th galvanometer with the resistance P in circuit. The value are then adjusted for the same deflexion with Q in circui Then, as the sum of the boxes is kept constant, $P/Q \simeq R_2/R$ The potentiometer method failed at about 10^8 Ω so that th accuracy of the bridge method was determined above th figure by the comparison of the calculated and experiment values of the combinations and the leakage values.

The method appears reliable up to 10^9 Ω to at least ±2 and certainly to ±1% up to 10^8 Ω. Moreover, the magnitud of the deflexions obtained at 10^9 Ω indicates that the uppe limit of the method is higher than that figure.

ACKNOWLEDGEMENT

The author wishes to thank Prof. E. C. Amoroso for hi interest and encouragement in this work.

---

* Price, W. A. *A treatise on the measurement of electrical resistance* (Oxford: University Press, 1894).

Precision measurement of small radii of curvature

By R. N. Wilson, Ph.D., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 21 *March*, 1956]

The conditions for the accurate measurement of small radii of curvature by microscope methods are discussed and the relevant formulae stated.

uild* has considered the application of microscope methods o the measurement of small radii of curvature. Recent equirements for precision measurement of radii of the order f 5 mm have led to a re-assessment of the technique and its ccuracy which may be of interest in the optical industry. mall radii are normally determined by micrometrical neasurements on hyper-hemispheres, a small concave surface eing assessed against the convex surface as test plate. If yper-hemispheres are not available, other methods must be mployed.

THEORY

The method described by Guild makes use of the aperture f a microscope objective as an object to be imaged by the urface under investigation. The size of the image viewed in he microscope is determined. If the working distance of the nicroscope is fairly large compared with its diameter (i.e. low numerical aperture), then the position and sizes of the bject and image can be defined by the paraxial relations:

convex surface

$$r = \frac{+2|m|\,|k|}{1-|m|^2} \qquad (1a)$$

$$r = \frac{+2|m|\,|h|}{1+|m|} \qquad (2a)$$

concave surface

$$r = \frac{-2|m|\,|k|}{1-|m|^2} \qquad (1b)$$

$$r = \frac{-2|m|\,|h|}{1-|m|} \qquad (2b)$$

n these formulae, $|m|$ is the numerical value of the magnification (always less than unity), $|k|$ the numerical value of he separation of object and image, $|h|$ the numerical value of he height of the object above the centre of curvature of the urface, and r the radius of curvature.

In order to obtain higher accuracy, it is necessary to mprove the accuracy of determination of the object and mage sizes, which implies a departure from paraxial conlitions. The figure shows the method employed. Two fine lits were set up at a convenient height (about 4 in.) above he glass table of a toolmaker's microscope and were disposed s accurately as possible about the centre of the table at a eparation of about 5 in. equivalent to twice the distance z.

Vertical lines such as BC are defined by the axis of the nicroscope. If the slit is at A, the image will appear on the ine BC such that $B\widehat{C}D = A\widehat{C}D = I$. The ray ACB defines he centre of the oblique pencil employed in forming the mage of width dependent on the numerical aperture of the nicroscope objective. The separation of the images (i.e. $2p$) vas measured by traversing the table. The separation of the lits, $2z$, was also determined in this manner.

It is easily shown that, for convex surfaces, the radius is iven by:

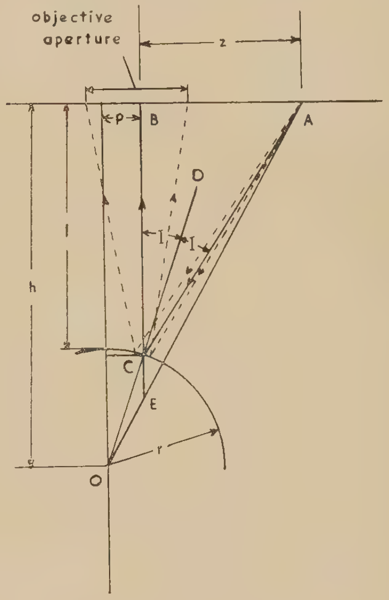
$$r^2 = \frac{2p^2}{(z+p)^2}[(h^2+z^2+zp)+h\sqrt{(h^2+z^2-p^2)}] \quad (3)$$

nd, for concave surfaces, by:

$$r^2 = \frac{2p^2}{(z-p)^2}[(h^2+z^2-zp)+h\sqrt{(h^2+z^2-p^2)}] \quad (4)$$

In these formulae, the quantity h is the height of the slits above the centre of curvature of the surface. Equations (3) and (4) reduce to equations (2*a*) and (2*b*) respectively if $h \gg z$ and p.

In practice, the quantity h is not known: the measurable quantity is $l = (h \mp r)$. The equations (3) and (4) can be rearranged as quartics in l; but it is more convenient to assume a value of r, substitute $h = (l \pm r)$ in the equations (3) and (4) and deduce r by an iterative process; normally, two iterations suffice. The value of l can be determined to high accuracy with slip gauges and a dial indicator.



Principle of method

ACCURACY

Experiments have shown that radii of the order of 5 mm can be measured absolutely to an accuracy of the order of one part in 700 with comparative ease. It is probable that accurate setting with jigs of the slits and surface of unknown radius would lead to accuracies of the order of one part in 1000 in absolute determinations. Calibration with steel balls, micrometrically checked, should lead to better accuracy. The extension of the calibration for convex surfaces to concave, however, cannot conveniently be carried out as it can in the paraxial case. Inspection of equations (3) and (4) shows that a sign reversal occurs in both numerator and denominator. Neglect of the former gives errors in the measured radius of the order of 0·4% (for radii of about 5 mm) with the values of the height and slit separation employed; neglect of the latter leads to errors of the order of 5%. In addition, the quantity h will be different for convex and concave surfaces: for example, for a pair of proof plates of about 0·25 in. radius, the values of *h* for the convex and concave plates were respectively 3·9349 and 3·5501 in. These considerations render a separate calibration necessary for concave surfaces if absolute determinations are not sufficiently accurate.

---

* Guild, J. *Dictionary of Applied Physics*, Vol. IV, p. 794 ondon: Macmillan and Co., 1923).

ACKNOWLEDGEMENTS

The author acknowledges helpful suggestions fron
K. J. Habell in the course of this work which has been car
out as part of the research programme of the Natic
Physical Laboratory. This paper is published by permiss
of the Director of the Laboratory.

An improved ionization gauge control circuit

By P. Hariharan, M.Sc., A.Inst.P., and M. S. Bhalla, M.Sc., National Physical Laboratory of India, New Delhi, Inc

[*Paper received* 30 *April*, 1956]

In this unit, the heating power for the ionization gauge filament is supplied by an audio amplifier fed from an internal oscillator. Stabilization of the electron current, for wide variations in the emissive characteristics of the filament, is achieved by a negative feedback loop which controls the gain of the amplifier.

Ion currents ranging from 100 to 0·01μ A are read on a single logarithmic scale by utilizing the retarding field characteristics of a triode. This eliminates range switching and is particularly advantageous for multi-point reading or continuous recording of pressures.

In a thermionic ionization gauge operated at constant electrode potentials and with a given electron current, the ion current is directly proportional to the pressure, for pressures below a certain critical value. Consequently, measurements of the ion current afford a convenient method of measuring high vacua.

In actual use, when the pressure is to be read continuously, it is necessary to have automatic stabilization of the electron current. The series impedance type of stabilizer(1, 2) is commonly used for this purpose, but it has the drawback of a limited control range and cannot, therefore, be considered really satisfactory, since poisoning effects can cause considerable variations in the emissive properties of gauge filaments. For this reason, the present circuit utilizes an emission stabilizer(3) which controls the entire filament current and has enough reserve power to hold the emission constant, even in the presence of such variations.

Another problem in the operation of an ionization gauge is the measurement of the ion current, which is usually small and can vary over a considerable range. The circuits normally employed for this purpose(4, 5) cover only a restricted current range at each sensitivity setting and have the further disadvantage that the meter can be damaged by sudden overloads. These difficulties are avoided, in the unit described, by using a grid current amplifier(6) to read the whole range of ion currents on a single logarithmic scale.

CIRCUIT DETAILS

Fig. 1 is a circuit diagram of the control unit and Fig. 2 shows the power supply used with it. The control circuit can be conveniently divided into four sections.

The emission current stabilizer. The filament of the ionization gauge V_1 is heated by the a.c. output from an audio amplifier using two beam tetrodes V_8, V_9 in the final stage. The input signal for these tubes is supplied through a variable-μ pentode V_4 and a phase splitter circuit V_6, V_7, by a Colpitts oscillator V_3 which operates at a frequency of 500 c/s.

The voltage drop across R_{30} and RV_6 due to the electron current drawn by the grid of the ionization gauge is used to vary the bias on the grid of V_4. This controls the gain of the amplifier and, hence, the filament current of the gauge, so that the electron current is maintained constant at 10 mA.

The use of a variable-μ pentode as the control tube, inst
of a triode,(3) permits the use of a higher a.c. input sig
without running into distortion at the low power end of
control range, and thus eliminates the necessity of shield
the control circuit.

Because of the voltage drop across R_{31} due to the curr
drawn by the grid of the ionization gauge, the filament
the gauge is held at a steady potential of +25 V with resp
to the collector, which is approximately at ground potent
The grid of the gauge, which is at a slightly lower poten
than the cathode of V_4, is at a potential of about +12
with respect to the filament.

Since a 500 c/s signal is used to drive the amplifier
comparatively small output transformer can be used. Sta
operation of the control circuit can also be ensured qu
easily by designing the amplifier so that its gain falls off
frequencies below 200 c/s, since R_{12} and C_9 constitute a l
pass filter which attenuates high frequencies in the feedba
line.

The control characteristics of the circuit are shown in Fig
in which the output from the amplifier is plotted as a functi
of the bias voltage on the grid of V_4 with respect to t
150 V line (*E*, Fig. 1). Smooth control of the filament pow
is possible, practically from cut-off, up to over 35 W.
contrast to other wide range emission stabilizers,(7, 8) d
tortion of the output waveform is negligible over the wh
of this range, and the utilization of the power tubes is ve
good. Assuming that the power requirements for a giv
gauge filament vary by a factor of 10, the emission curre
can be stabilized to within ±1·5%.

A considerable increase in control sensitivity over t
regulator described by Solomon and Caton(3) has be
obtained, in this circuit, by supplying the grid of the ionizati
gauge from the 300 V line (*D*, Fig. 1) so that a corresponding
greater d.c. signal voltage is developed across R_{30} and *R*
This can, however, result in instability when the circuit
switched on, since a high positive bias would then be appli
to the grid of V_4, and, as can be seen from Fig. 3, the pow
output from the amplifier decreases as the positive bi
increases. This difficulty has been avoided by connecting
diode V_5 between the feedback line and the 150 V supp
lead. By choosing a suitable cathode resistor for V_4,
operating range can then be limited to the region to the le
of the vertical dotted line in Fig. 3.

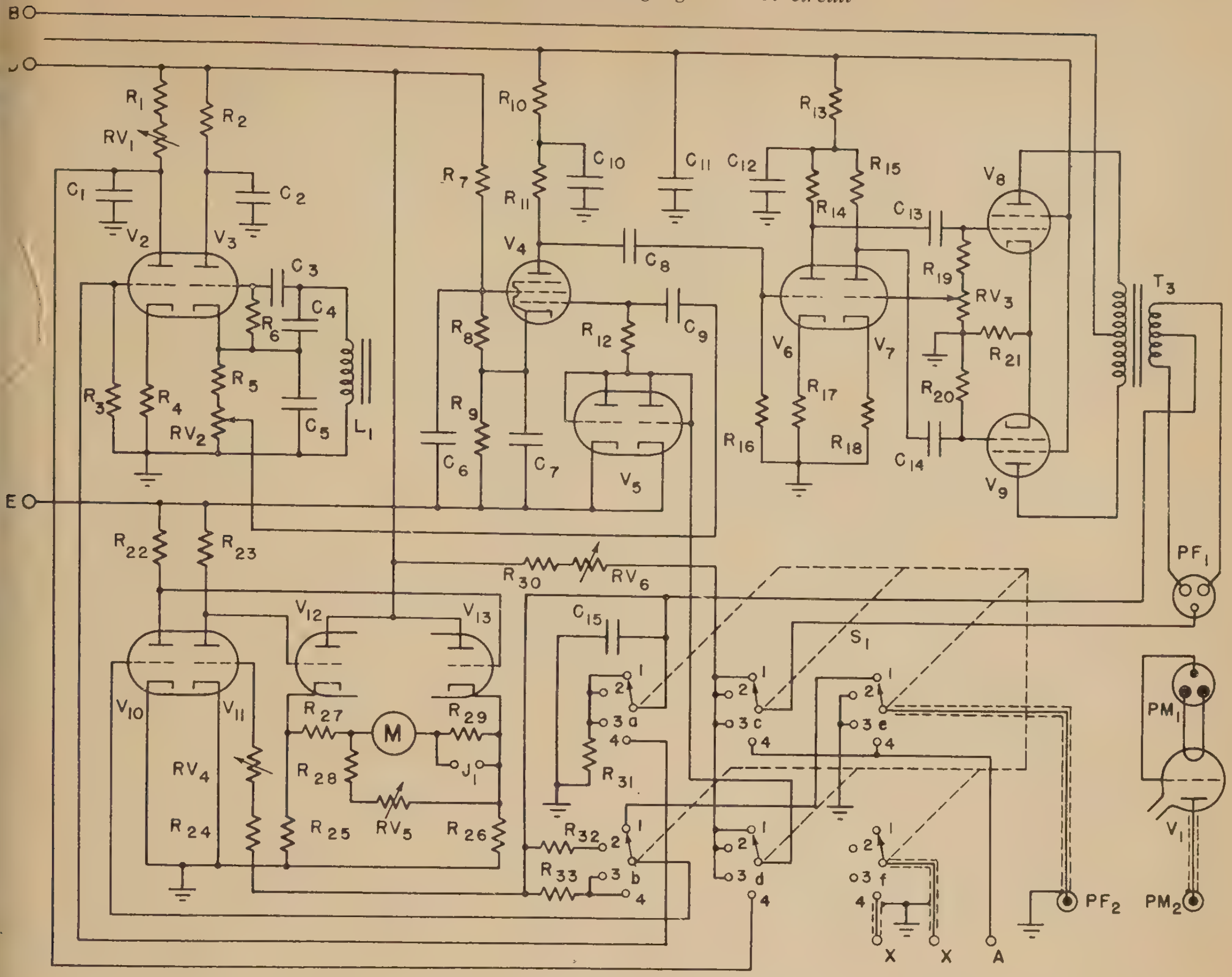


Fig. 1. Circuit diagram of the control unit

R_1 = 100 kΩ
R_2 = 24 kΩ
R_3 = 100 Ω, 10 W
R_4 = 15 kΩ
R_5 = 10 kΩ
R_6 = 1 MΩ
R_7 = 18 kΩ
R_8 = 10 kΩ
R_9 = 470 Ω
R_{10} = 15 kΩ
R_{11} = 47 kΩ
R_{12} = 1 MΩ
R_{13} = 10 kΩ
R_{14}, R_{15} = 100 kΩ
R_{16} = 470 kΩ
R_{17}, R_{18} = 2·2 kΩ
R_{19} = 150 kΩ
R_{20} = 240 kΩ

R_{21} = 250 Ω, 10 W
R_{22}, R_{23} = 220 kΩ
R_{24} = 150 kΩ
R_{25}, R_{26} = 10 kΩ
R_{27} = 20 kΩ
R_{28} = 250 Ω
R_{29} = 100 Ω
R_{30} = 10 kΩ, 10 W
R_{31} = 2·5 kΩ, 10 W
R_{32} = 2500 MΩ, calibrated
R_{33} = 250 kΩ, calibrated

RV_1 = 100 kΩ
RV_2 = 1 kΩ
RV_3 = 100 kΩ
RV_4 = 500 kΩ
RV_5 = 250 Ω w.w.
RV_6 = 10 kΩ w.w.

C_1 = 32 μF, 450 V
C_2 = 8 μF, 450 V
C_3 = 0·05 μF
C_4 = 0·1 μF
C_5 = 0·02 μF
C_6 = 0·1 μF
C_7 = 25 μF, 25 V
C_8 = 0·002 μF
C_9 = 0·01 μF
C_{10}–C_{12} = 8 μF, 450 V
C_{13}, C_{14} = 0·005 μF
C_{15} = 32 μF, 450 V

V_1 = ion gauge
V_2, V_3 = 6SN7 GT
V_4 = 6SG7
V_5 = 6J6
V_6, V_7 = 6SN7 GT

V_8, V_9 = KT 66
V_{10}, V_{11} = 6F8 G
V_{12}, V_{13} = 6SN7 GT

L_1 = 10 H

M = 0–100 μA meter

S_1 = 6-pole, 4-way, non-shorting switch. Positions: 1, read; 2, scale check; 3, zero check; 4, outgas.

T_3 = output transformer. Primary impedance, 6600 Ω plate-to-plate. Secondary impedance to match gauge filament.

Note.—All resistors are 10%, 1 W carbon resistors, unless otherwise specified.

The ion current meter. The ion current meter utilizes a pe 6F8 tube V_{10}, V_{11}, operated as a logarithmic difference nplifier.(6) The grid of V_{10}, which is brought out through e top cap, is connected to the collector of the ionization uge, while the grid of V_{11} is connected through RV_4 and $_{24}$ to the electrical mid-point of the gauge filament. The ates of V_{10} and V_{11} are directly coupled to the grids of a lanced cathode follower V_{12}, V_{13}, which drives a 0–100 μA eter (M, Fig. 1). The zero of the meter is set by means of V_4 and its sensitivity is controlled by RV_5.

The grid current in V_{10} is equal to the positive ion current collected by the plate of the ionization gauge, while the id current of V_{11} is proportional to the voltage drop across $_{31}$ due to the electron current i^- drawn by the grid of the nization gauge and hence to the electron current itself. nce the plate currents in V_{10} and V_{11} are proportional to the logarithms of the respective grid currents,(9) the current in the meter circuit will be proportional to $\log(i^+/i^-)$. Consequently, residual fluctuations in the electron current, due to the finite gain of the feedback circuit, will not affect the meter reading for a given pressure.(6) The use of a balanced circuit also helps to cancel out the effects of heater voltage fluctuations.(10) A potentiometer recorder can be plugged in at J_1 if a continuous record of the pressure is to be made.

The calibration curve of the ion current meter is shown in Fig. 4. The scale is closely logarithmic for ion currents ranging from 100 to 0·01 μA. With a typical ionization gauge, operated with an electron current of 10 mA, this would correspond to pressures ranging from 10^{-3} to 10^{-7} mm of mercury.

The outgassing current stabilizer. Provision is also made in this circuit for outgassing the electrodes of the ionization gauge by electron bombardment. For this, the grid and plate of the gauge are supplied with 350 V a.c. from a separate transformer T_1, and a predetermined electron current is drawn from the filament.

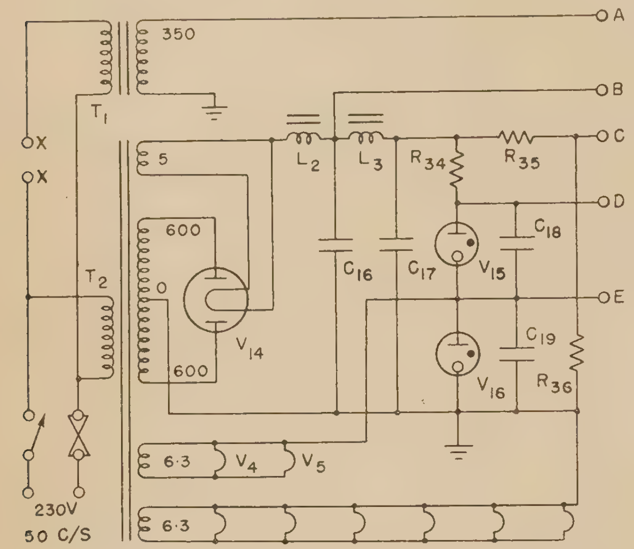


Fig. 2. Power supply used with the control unit

R_{34} = 4 kΩ, 10 W
R_{35} = 2·5 kΩ, 10 W
R_{36} = 12·5 kΩ, 10 W

C_{16} = 4 μF, 1000 V
C_{17} = 32 μF, 600 V
C_{18}, C_{19} = 0·1 μF

V_{14} = 5U4 G
V_{15}, V_{16} = VR 150

L_2, L_3 = 4–10 H, 250 mA

T_1 = 350 V, 150 mA
T_2 = 600–0–600 V, 250 mA; 5 V, 3 A; 6·3 V, 5 A; 6·3 V, 2 A

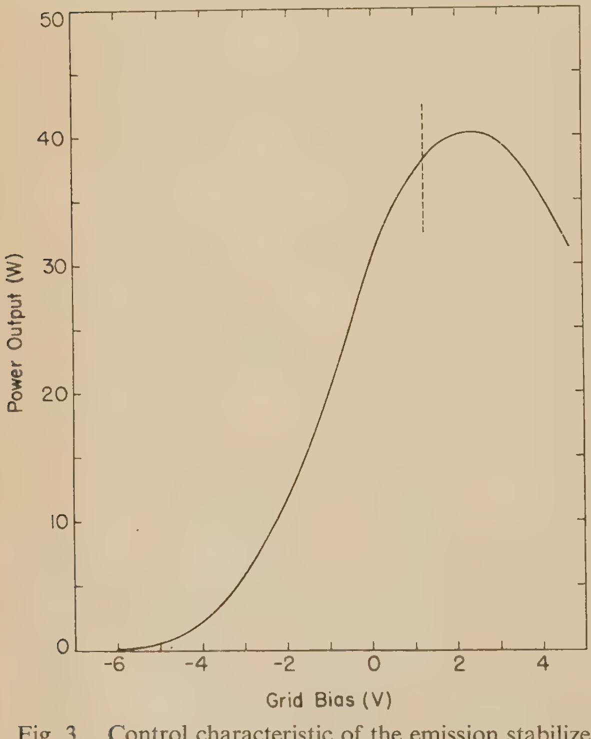


Fig. 3. Control characteristic of the emission stabilizer, showing the variation of the output power with the bias voltage applied to the grid of the control tube. The bias voltage is measured with reference to the 150 V line E (Fig. 1)

Stabilization of the outgassing current is effected applying the potential drop across a resistor R_3, in cathode lead of the ionization gauge, to the grid of a amplifier V_2. This controls the bias on V_4 and, hence, filament heating power. The value of R_3 specified is for outgassing current of 100 mA, but the outgassing curr can be set at any desired value by choosing R_3 according

The master switch. The entire circuit is controlled b single six-pole switch S_1 with four positions. The first the normal measuring position, the second and third are checking the sensitivity and the zero of the ion current me and the last position is for outgassing the gauge.

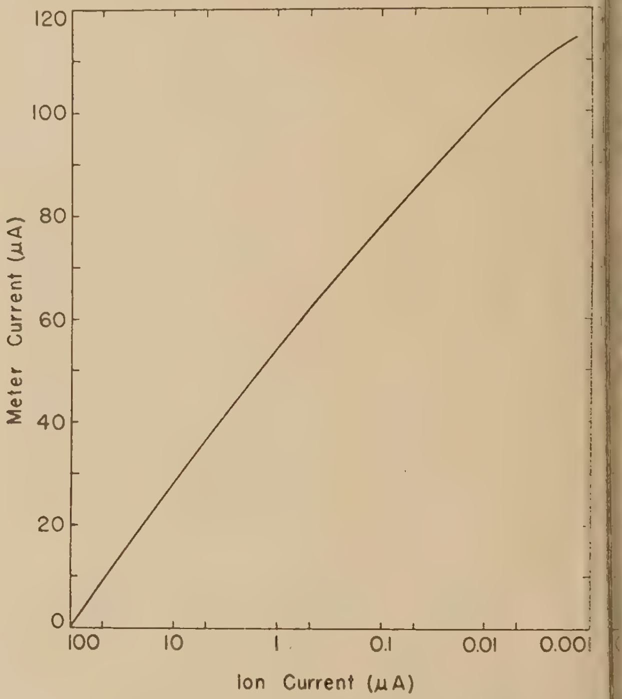


Fig. 4. Calibration curve of the ion current meter. The output current in the meter is shown as a function of the ion current drawn by the collector of the gauge

In the measuring position, the grid of V_{10} is connect directly to the plate of the ionization gauge, while the gr of V_{11} is connected through RV_4 and R_{24} to the centre poi of the filament, which is at a steady potential of +25 When checking the zero of the meter, the grid of V_{10} is al connected to this point through a 250 kΩ resistor R_{33}. this position, the grid of V_{10} draws a current of 100 μA a the zero of the meter can be set by means of RV_4. In t "scale check" position, the grid of V_{10} is connected to t same point through a 2500 MΩ resistor R_{32} and it draws current of 0·01 μA; RV_5 can then be adjusted so that t meter reads full scale.

When outgassing the gauge, its grid and plate are connect to a 350 V transformer T_1. This is energized, in this positio by the contact f on the last deck of the master switch S_1. the same time, the 2·5 kΩ resistor R_{31} in the cathode circu of the gauge is replaced by the 100 Ω resistor R_3, acro which the control signal for the outgassing current stabiliz is taken.

CIRCUIT ADJUSTMENTS

Preliminary adjustments are best made with the mast switch on "zero check" and with a dummy load, replaci e ionization gauge filament, across the output of the mplifier. Under these conditions, as mentioned earlier, the ower output from the amplifier is controlled by V_5, which mits the bias voltage on V_4.

The a.c. signal input to the grid of V_4 is initially set at a w value (say 0·1 V r.m.s.) by means of RV_2, and RV_3 is djusted so that the signal voltages on the grids of both the ower tubes are equal. After this, the input signal can be creased until the output power is the maximum which can e safely applied to the gauge filament.

The variable resistors RV_1 and RV_6 are then set at their aximum values and the ionization gauge is plugged into the nit. The current drawn by the grid of the gauge can now e set at 10 mA by adjusting RV_6. This adjustment can be onveniently performed by measuring the voltage across the ·5 kΩ resistor R_{31} in the cathode circuit.

Finally, the master switch is turned to "outgas" and the lectron bombardment current is brought up to 100 mA by eans of RV_1.

PERFORMANCE

This control unit has been found very convenient and quite eliable in actual use. The wide range stabilizer can hold the mission current at its rated value almost regardless of the ondition of the filament, and the logarithmic ion current cale eliminates range switching, so that readings can be taken ery quickly. These features are particularly convenient for multi-point reading with more than one gauge head, or when a continuous record of the pressure is to be made.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. W. M. Vaidya for his interest in this work, and the Director, National Physical Laboratory of India, for permission to publish this paper.

REFERENCES

(1) Ridenour, L. N., and Lampson, C. W. *Rev. Sci. Instrum.*, **8**, p. 162 (1937).
(2) Nelson, R. B., and Wing, A. K. *Rev. Sci. Instrum.*, **13**, p. 215 (1942).
(3) Solomon, A. K., and Caton, D. C. *Rev. Sci. Instrum.*, **23**, p. 757 (1952).
(4) Rainwater, J. *Rev. Sci. Instrum.*, **13**, p. 118 (1942).
(5) Bowie, R. M. *Rev. Sci. Instrum.*, **11**, p. 265 (1940).
(6) Hariharan, P., and Bhalla, M. S. *Rev. Sci. Instrum.*, **27**, p. 448 (1956).
(7) Steckelmacher, W., and van der Meer, S. *J. Sci. Instrum.*, **27**, p. 189 (1950).
(8) Lees, C. S., and Armitage, M. D. *J. Sci. Instrum.*, **27**, p. 300 (1950).
(9) Russell, J. *Rev. Sci. Instrum.*, **8**, p. 495 (1937).
(10) Attree, V. H. *J. Sci. Instrum.*, **32**, p. 41 (1955).

A double-beam microspectrometer

By G. H. Haggis, M.A., Ph.D.,* Middlesex Hospital Medical School, London, W.1

[*Paper received 29 August*, 1956]

A modified single-beam spectrometer, fitted with a small rocking mirror to provide a double-beam through a reflecting microscope, is described. The ratio of the intensities of the two beams is determined electronically, and fed through to a pen recorder. The merits of this arrangement are compared with those of other micro-double-beam systems.

or much biophysical and biochemical work there is need or a double-beam recording spectrometer, with a micro-ocus for very small samples, which can be readily converted or use in the ultra-violet, visible, or infra-red regions. Fig. 1 hows an overall view of a Perkin Elmer type 12C single eam spectrometer modified to meet these requirements, and lso a closer view of the instrument from the same angle vith the monochromator cover removed. The optical rrangement is shown in Fig. 2.

Light from the "globar" source passes through the mono-hromator, and is reflected by three small spherical mirrors $_2$, M_3, M_4 into the side-arm of a Beck reflecting microscope ×52 objective and condenser), and thence to a detector laced below the microscope. Mirrors M_2 and M_3 form a eal image of the monochromator exit slit (S) at M_4, and the nicroscope objective forms a reduced image of this slit in he plane of the microscopic sample under investigation. Mirrors M_2 and M_3 are mounted inside the monochromator over, and after reflexion from these two mirrors the light merges through the exit port provided on the original pectrometer. Mirror M_4 is mounted on an arm attached to he microscope, which is clamped to the console top.

The distances between the mirrors, and their focal lengths, are so adjusted that a real image of the collimator mirror (M_1) is formed at M_3 and at the small mirror of the microscope objective, matching the numerical aperture of the microscope to that of the spectrometer. This involves a ×7 enlargement of the slit image at M_4, and an overall reduction at the microscope sample plane of $\times\frac{1}{7}$. The diameter of the field of view of the Beck ×52 objectives is 250 μ, and for a slit width of 0·14 mm the size of sample required is thus 20 × 250 μ. Only light from the central 1·75 mm of the slit length can pass through the microscope, with an inevitable loss of energy of approximately 30%, in addition to losses due to the central obstruction of the objective and to the many reflexions. If further energy losses can be tolerated, the size of sample may be reduced by placing stops below the microscope as described below.

The mirror M_3 is mounted on pivots so that it can rotate through a small angle about a vertical axis. By means of a light solenoid and spring it may be rocked between two positions to give a 150 μ lateral displacement of the image of the slit in the microscope sample plane. In one position the light passes through the sample, and in the other passes alongside, or through compensating solvent. The rocking mirror solenoid is linked to the Perkin Elmer chopper (Fig. 2) so that alternate chopper cycles provide the sample and reference beams. The chopper rotates at 13 c/s, and the mirror moves from one position to the other in less than 1/26 s, while the light is cut off. The angular movement is about 1½°.

---

* Now at Physiology Department, University of Edinburgh.

Below the microscope the two beams fall on to two separate halves of a concave mirror, tilted so that the final images of the slit coincide along the narrow sensitive area of a lead telluride detector, or, for detectors with a larger sensitive area such as photomultipliers, a mirror is inserted to focus an image of the small mirror of the condenser on to the light sensitive area. The detectors are mounted below the console top on which the microscope is resting, and a lamp is also mounted here in such a way that it can be swung into position for viewing the sample through the microscope eyepiece. Subsidiary images of the monochromator exit slit, of size approximately 12 × 1 mm, are formed at the point where the light passes through the console top, and it is convenient to fit a window at this point with hair-lines marking the positions of the two beams. In this way the sample can be exactly positioned relative to the hair-lines. Macroscopic samples may also be placed at this point for double-beam operation, and stops must be placed in this plane if a very accurately defined area of the sample is to be studied, since the series spherical mirrors M_2, M_3 M_4 introduce some abberations the slit image. The mirror M_4 is used in a rather unconv tional way in that it is of relatively short focal length, 45° off-axis. Since an image of the exit slit is formed at only a thin line of the mirror is used, and the abberati introduced are actually quite small. Mirror M_3 is pla close to the exit slit, so that M_2 is used as nearly on-axis possible. A polarizer may be placed below the microsco condenser (shown in Fig. 1).

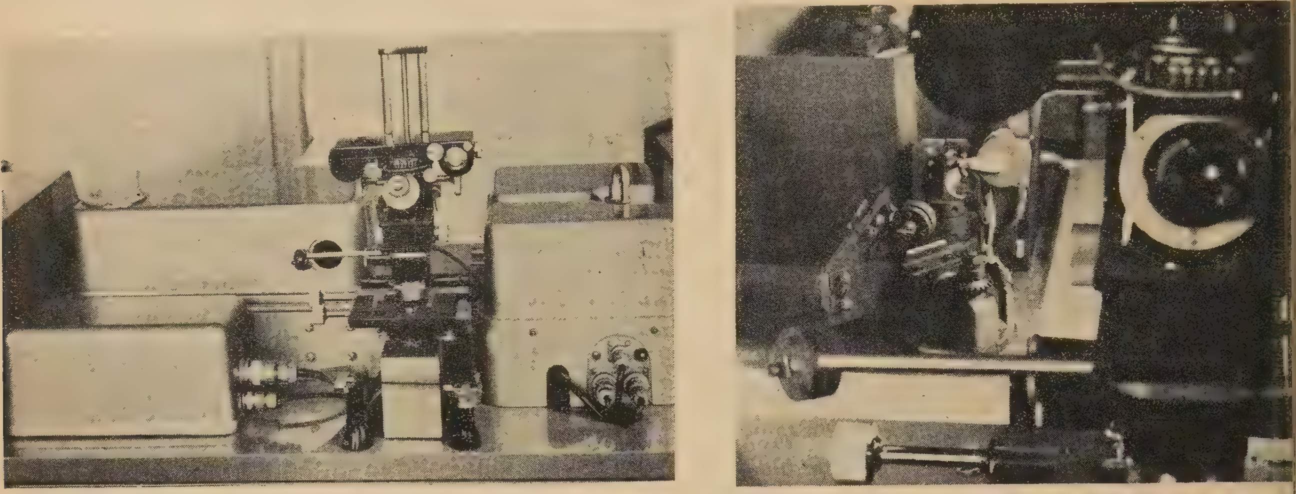

(a) (b)

Fig. 1. (a) Overall view of spectrometer and reflecting microscope, with (b) a closer view of the small rocking mirror, fitted to provide a double-beam through the microscope

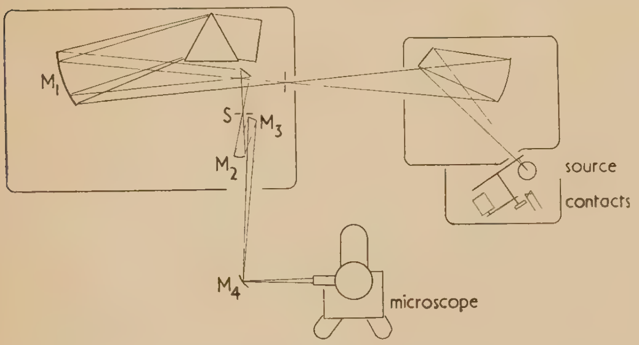


Fig. 2. Optical arrangement of modified spectrometer. Focal lengths and distances:

$f_{M2} = 5$ cm
$f_{M3} = -30$ cm
$f_{M4} = 10$ cm
$SM_2 = 7$ cm
$M_2M_3 = 5$ cm
$M_3M_4 = 27$ cm

The electronic circuit for determining the ratio of t intensities of the two beams is of the type described Hornig and others.(1) After wide band amplification t detector signal is brought through a cathode follower to set of contacts linked, in the present case, to the Perk Elmer chopper motor, which is also controlling the moveme of the rocking mirror. Rectified signals from the contac proportional to the intensities of the two beams, are integrat by condenser circuits, with a time constant of one secon and the out-of-balance signal is fed through to the p recorder. A Leeds Northrup recorder is included as part the Perkin Elmer 12C spectrometer, and this has been modifi in the way described by Hornig and others.(1) The p moves to a null position determined by the percenta absorption in the sample beam. Some trouble with pick-u was experienced in a rather long lead from condenser circui to pen recorder, and this lead should be kept as short possible. Care was taken to screen the lead from detect to amplifier, although 50 c/s pick-up is integrated out to considerable extent by the condenser circuits. Only lig reflected from M_3 can contribute to the final signals, but it important that this mirror should not reflect stray light in the microscope.

Fig. 3 shows a calibration spectrum of polystyrene take with slit width 0·10 mm at 200 cm^{-1} a minute using a le telluride detector and a calcium fluoride prism. Oth spectra taken in connexion with protein structure studies are shown in Figs. 4 and 5. The instrument has been successful operation for two years, and may be readily reco verted to normal single-beam operation if this is require It is also not difficult to interchange prisms, sources detectors for work in different spectral regions. For infra

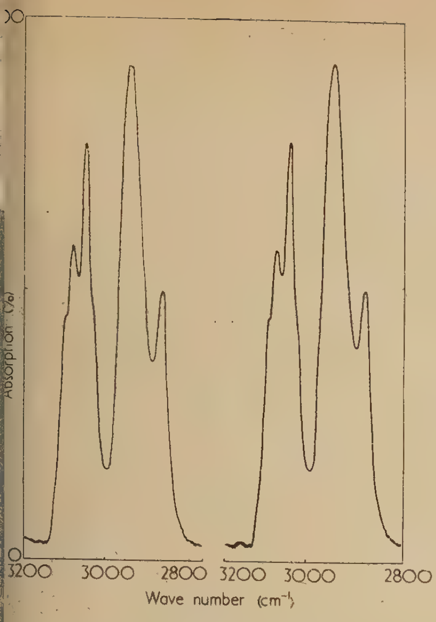


Fig. 3. Polystyrene absorption spectrum near 3000 cm^{-1}. Run repeated to show resolution (25 cm^{-1}) and reproducibility (±1 %), under conditions noted in text.

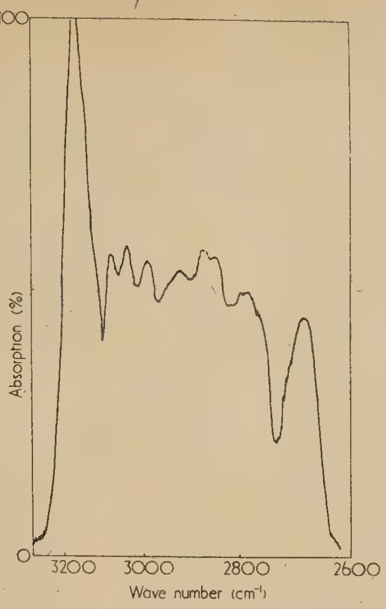


Fig. 4. Spectrum of glycine crystal at −196° C in the region 3300 to 2500 cm^{-1}

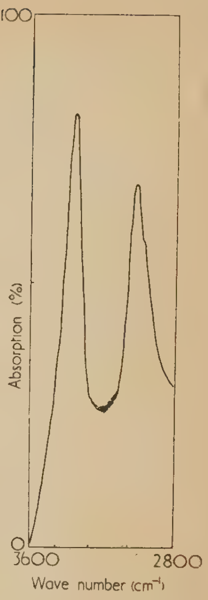


Fig. 5. Spectrum of wet haemoglobin crystal near 3300 cm^{-1}, the water present being D_2O. A proportion of the protein hydrogens have exchanged with deuterium(2)

ed spectroscopy beyond 5 μ where detectors are less sensitive, t is undoubtedly an advantage to use reflecting objectives lesigned to reduce the energy lost in passing through the nicroscope. In the visible and ultra-violet regions, for amples giving appreciable scatter, or for very small samples, uitable refracting objectives and condensers must be used. The Beck microscope in the present instrument may, of course, e used for microphotography in the visible and ultra-violet egions if suitable lamps are fitted below the microscope.

OMPARISON WITH OTHER MICRO-DOUBLE-BEAM SYSTEMS

The present arrangement is mechanically simpler than hose in which sample and reference cells are moved alterately into the microscope field, and less precision is required n a movement which takes place before demagnification. For crystal suspensions it avoids possible movement of the ample in the cell.(3) The main disadvantage of the present rrangement is that at least one beam must pass through he microscope off-centre, and the abberations in simple eflecting objectives increase rather rapidly with distance rom the centre of the field.(4) The two beams are normally lined symmetrically, but where the sample area must be ccurately defined the sample beam can pass through the entre of the microscope.

For some biological material it is a disadvantage that a lear space must be provided in the microscope field for the eference beam, but at other times it is an advantage for the eference beam to pass through a closely adjacent part of he material, or a small similar sample, which does not conain the absorbing material to be studied. If the reference beam is taken alongside the microscope it is, of course, not possible to place very small compensating samples or cells in this beam.

As compared with systems in which two halves of the slit image provide the reference and sample beams,* the present arrangement has the advantage that the two beams are not immediately adjacent, and that the separation between them is adjustable within limits set by the field of view of the microscope. Electronic ratio recording has the advantage that it may be used with suitable detectors in any wavelength region.

ACKNOWLEDGEMENTS

I am indebted to Prof. Sir Charles Dodds for permission to modify one of the spectrometers in the Courtauld Institute of Biochemistry, to Dr. S. F. D. Orr of the Chester Beatty Institute, for advice on matching the Beck objectives to the Perkin Elmer spectrometer, and also to Mr. P. Lay and Mr. E. Parker who carried out the electronic and mechanical work involved. The lead telluride detector is on loan from the Director, Radar Research Establishment, Malvern, and I am also very grateful to Mr. J. Tierney who took the photographs in Fig. 1.

REFERENCES

(1) Hornig, D. F., Hyde, G. E., and Adcock, W. A. *J. Opt. Soc. Amer.*, **40**, p. 497 (1950).

(2) Haggis, G. H. *Biochim. Biophys. Acta.* To be published.

(3) Elliott, A. *Proc. Roy. Soc. A*, **211**, p. 490 (1952).

(4) Wilkins, M. H. F. *Disc. Faraday Soc.* (9), p. 390 (1950).

---

* A system of this type has been proposed for use with the Perkin Elmer reflecting microscope attachment.

Temperature cycle controller

By J. C. Barnes, M.Sc., Radio and Electrical Engineering Division, National Research Council, Ottawa, Canada

[*Paper received* 16 *August*, 1956]

A description is given of an instrumeut suitable for use in research laboratories where process time-temperature requirements may be extremely varied and where simplicity of cam layout is therefore of prime importance.

This instrument was designed to be used in conjunction with a commercial moving-coil indicating and controlling meter—in this case, a Wheelco "Capacitrol." A cam and follower mechanism is employed to transmit pre-determined time-temperature requirements to the Capacitrol input shaft, formerly used for manual setting. The cam, being of thin sheet aluminium, can be cut easily to an accurate contour, and becomes quite rigid when formed into a cylinder and attached to a cast aluminium drum.

In the initial stages of design, an attempt was made to use a disk cam, but this was abandoned in favour of a cylindrical form, for two reasons: firstly, because the temperature gradient requirements produced excessively steep angles of attack near the centre of the cam; and secondly, because with the cylindrical cam, both scales are linear and straight.

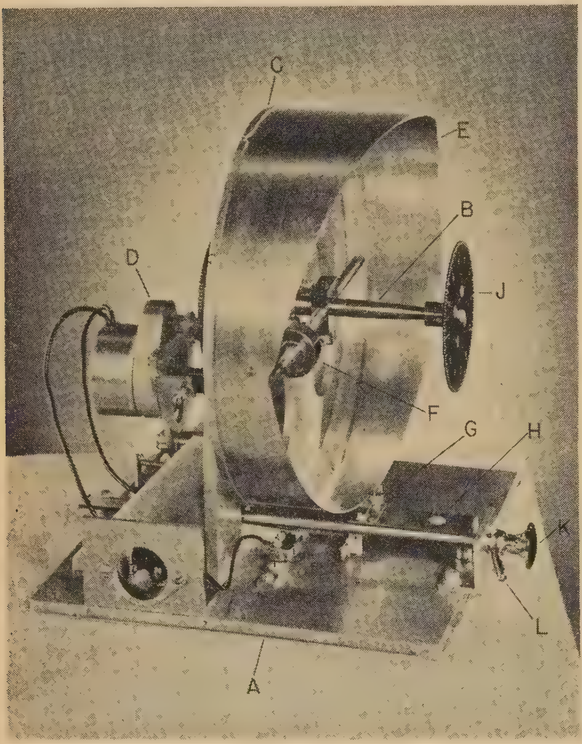


Fig. 1. General view (cover removed)

The main features of the instrument may be seen in Fig. 1. A base and bracket *A*, rigidly attached to the original Wheelco instrument, support a ball-bearing-mounted shaft *B* and drum *C*. The shaft and drum are driven by a clock motor *D* with suitable external gearing to give the desired output speed (e.g. one revolution in twelve hours) to the drum. The drum itself is an aluminium casting to which is attached the sheet aluminium (0·032 in.) cam *E*. Since the cam blanks are supplied to the laboratory as flat rectangular sheets with zero lines and mounting holes provided, the desired time-temperature contours can be laid out with extreme facil The actual cutting of the cam contour is a simple operat which can be carried out in a few minutes with a pair of t snips. It is then formed to the correct diameter and fix to the drum, which has a shoulder and groove to ens correct seating and zeroing of the cam. An adjusta counterbalance *F* is provided to compensate for different c contours.

A small ball-bearing mounted carriage *G* rides on a fix track *H* which is located below the drum parallel to temperature scale on the cam. A ball-bearing cam follow is mounted on this carriage, and two tension springs provided to maintain continuous contact between the ca and follower. The translatory motion of the carriage is th converted into the desired rotary motion for the (forme manual) input shaft by means of a rack and pinion.

Time indications are read from an adjustable, frictio mounted dial *J* on the end of the drum shaft, and temperatu indications are given on the control-setting scale of t original instrument.

Since the required initial temperature may be considera above room temperature, it is possible to disconnect t motor from the drum and turn the drum by hand to t required starting point on the cam. The motor drive is th re-engaged. This obviates the necessity of waiting for t controller to reach the initial temperature.

A limit switch is so located that an extra notch filed in t cam "below zero" will shut the motor off at the end of cycle.

The manual feature of the original Wheelco instrument h been retained by providing a sliding control knob *K* arranged that the carriage may be pulled forward to t desired temperature setting, and fixed in that position means of lock *L*. When not required, the sliding knob released and pushed back so that the automatic control operative over the full temperature range.

The accuracy of the instrument depends on the quality the design and construction, and in the present case was qui adequate, since the inaccuracy introduced by the "on-of action of the Wheelco instrument was greater than that the controller. The accompanying furnace-temperatu record, Fig. 2, is an exact duplicate of the cam contour, th slight variation in line width being a result of the combine effect of controller action and furnace characteristics.

While it is realized that some of the basic features describe

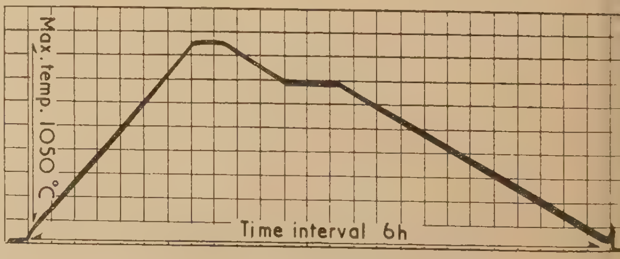


Fig. 2. Furnace temperature record

ove have been used in previous designs, it is felt that the troduction of a cylindrical cam with its complete absence “cramping” of the scales offers definite advantages for any applications. The facility with which new cams may cut right in the laboratory should be of considerable value experimental work.

ACKNOWLEDGEMENT

The author would like to express his thanks to Mr. P. A. Redhead and Mr. L. R. McNarry for some of the basic ideas incorporated into the design; to Mr. G. Lee for many design details; and to Mr. G. H. Rocque for his care in constructing the instrument.

Measurement of the optical density of smoke in a chimney

By A. Littlewood, B.Sc., Fuel Research Station, London, S.E.10

[*Paper received* 20 *July*, 1956]

An instrument is described for recording the optical density of smoke in a chimney. It was designed for the study of smoke emission from domestic-heating equipment at the Fuel Research Station, and its readings are independent of changes in the characteristics of the components and of variations in the electricity power supply. This is achieved by using a double-beam, null-balancing system with a single light source and a single barrier-layer photoelectric cell.

1. MEASUREMENT OF SMOKE IN A CHIMNEY

he amount of smoke emitted from a given domestic fire or tove, burning coal, varies widely with time, being greatest nmediately after refuelling, and diminishing as the volatile natter of the coal is driven off and a clear bright fire remains. he temperature of the gas and the rate of flow in the chimney re simultaneously subject to wide variations. It is a matter f great difficulty, therefore, to obtain a representative ample(1, 2) of the flue gas from which the smoke may be xtracted and weighed, particularly since this has to be done vithout disturbing the flow-pattern in the chimney and the ombustion in the fuel bed. A review of methods which have een used in the past for measuring smoke in chimneys(3, 4) ndicates that the most convenient method, for a long series f measurements, is the optical density method which avoids ny disturbance of the flow in the chimney. It has been hown(5, 6) that the optical density is simply related to the nass concentration, the relationship being linear if the smoke s not too dense, so that, once the instrument is calibrated, ampling of the flue gas is unnecessary. Even without alibration, valuable comparative results can be obtained. The total mass of smoke passing up the chimney can be btained directly from the mass concentration if the rate of low of gas in the chimney is known, but this must be neasured(7) without interfering with the flow-pattern.

.1 *Measurement of the optical density of smoke*

The measurement of optical density was one of the first ses of the photoelectric cell and it has since been widely sed for this purpose. The most common method described y many authors(8–18) is to project a beam of light through he smoke onto the photoelectric cell, the change in cell utput being used to give a measure of the optical density of he smoke. Inaccuracies occur due to the following causes:

(*a*) instability of the power supply to the light source;
(*b*) instability of the power supply to the photoelectric cell, and if used, to its amplifier;
(*c*) changes in the characteristics of the light source, of the photoelectric cell and, if used, of the amplifier; and
(*d*) incompatibility of the spectral characteristics of the light source, photoelectric cell and density plates used for calibration purposes.

ttempts have been made to overcome (*a*) and (*b*) by voltage tabilization but with only partial success.

Instruments have been devised to overcome the above difficulties. Grieve and Rowell(19) described a self-balancing form of smoke-meter(20) but unfortunately it relied upon accurate sampling of the smoke from the chimney. Bredl and Marsden(21) used two lamps and two photoelectric cells in a self-balancing system. This technique overcomes the inaccuracies due to power supply variations, but relies on the lamps and on the photoelectric cells having similar characteristics and maintaining them unchanged. The cells are of the barrier-layer type; thus they require no power supply or amplifier valve, but need to be contained in constant temperature housings.

Dobson,(22) Toy(23) and Hardy(24) described double-beam photometers operating with a single photoelectric cell to measure the optical density of photographic plates and Hill(25) extended the idea to measure to optical density of smoke stains. Schoen(26) suggested the use of the principle in a self-balancing form. The instrument to be described applies this idea to measure the optical density of the smoke in a domestic chimney in a manner which overcomes all the aforementioned sources of inaccuracy.

2. THE FUEL RESEARCH STATION OPTICAL DENSITY RECORDER

2.1 *Principle of the method*

A pencil of rays *a* (see Fig. 1) of a beam of parallel light from the source *S* is alined to pass through a rotating chopper *Ch* and, *via* windows in the sides of the brick chimney *C*,

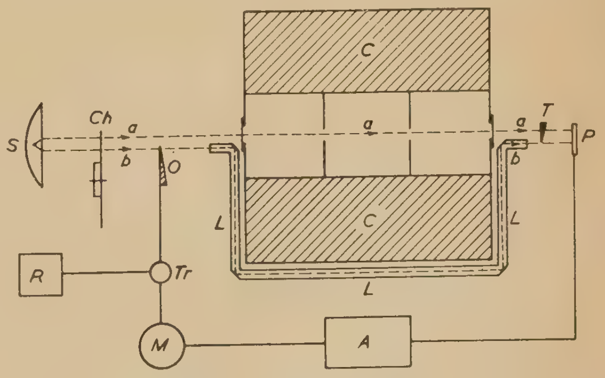


Fig. 1. Diagram of the instrument design

onto a photoelectric cell *P*. Another pencil of rays *b* from the same source *S*, after passing through the chopper *Ch* and optical wedge *O*, is conducted round the outside of the chimney, by internal reflexion, in a transparent plastic light guide *L*, to the same photoelectric cell *P*. The chopper is driven by a synchronous motor arranged so that the photoelectric cell receives light alternately through the chimney and through the optical wedge, the frequency of chopping being that of the mains supply.

The output from the photoelectric cell is then fed into a phase-sensitive amplifier *A*, and the amplified signal drives a two-phase induction motor *M* which moves the optical wedge *O*. A light trimmer *T* is introduced into the pencil *a* and is adjusted so that, with no smoke in the chimney, the illumination received by the photoelectric cell alternately from pencils *a* and *b* is the same. Then, with smoke in the chimney obscuring pencil *a*, the photoelectric cell emits an alternating signal which causes the wedge to move. Providing that the phase of the mains supply frequency to the amplifier *A* and the motor *M* is suitably matched with the phase of the light chopper, the wedge moves to rebalance the system by eliminating the a.c. signal from the photoelectric cell. In this way, changes in the optical density of the smoke are followed by changes in the position of the wedge. The transducer *Tr*, coupled mechanically to the balancing motor *M* and the optical wedge *O*, is connected to a high-speed recording potentiometer *R*. The recorder follows the transducer, which is driven by changes in the position of the wedge and therefore of the optical density of the smoke.

The balanced position of the optical wedge depends on the elimination of any difference between the amounts of light in the two pencils *a* and *b*. If there is any change in the source of light due to power fluctuations or aging, then each pencil will be similarly affected and the position of the wedge will remain unaltered. Also, if there is any change in the output characteristic of the photoelectric cell, the corresponding change in the difference signal will be of the second order, and its effect will be negligible. Thus, the design of the instrument is such that all the inaccuracies previously mentioned under (*a*), (*b*) and (*c*) of Section 1.1 are resolved; point (*d*) will be discussed later.

2.2 *Components*

2.21 *The source of light.* A tungsten-filament motor-car headlamp was considered to be the cheapest and most convenient means of obtaining a sensibly parallel and intense beam of white light of approximate diameter 4 in. The supply of electricity is taken from the mains through a step-down transformer; no attempt is made at stabilization.

As will be explained in Section 2.22, the frequencies of the light chopper and the lamp supply are the same. It was thought during the development of the instrument, that this might cause interference—as explained by Wooster(27)—but it was shown by using a d.c. supply to the lamp that there was no effect on the instrument performance.

2.22 *The light chopper.* The chopper motor is a permanent-capacitor synchronous induction motor, which rotates the chopper at half the mains frequency. The chopper is constructed with four quadrants and thus interrupts the light pencils *a* and *b* at the frequency of the mains supply. By these means the light pencils are chopped at a fixed phase-angle with respect to the mains frequency although the rotor of the motor can lock into either of two angular positions of phase difference π.

2.23 *The chimney.* A vertical section across the chimney is shown in Fig. 2. The flue-way, with its stainless steel lining *l*, is 9 in. square in cross-section and is enclosed 9 in. of brickwork. There are 9 in. square holes in the bri work on opposite sides which allow the pencil of light *a* traverse the flue-way. Plates *p* on the outside of the bri work reduce the holes to $1\frac{1}{4}$ in. square and these apertu are covered by glass *g*. The stainless steel lining has cor sponding holes *h* into the flue-way. The cross-section the pencil of light is reduced to $\frac{1}{2}$ in. square by the stop-pla *s* a few inches from each side of the chimney. The wh system is alined so that a beam of light, $\frac{1}{2}$ in. square in sectio

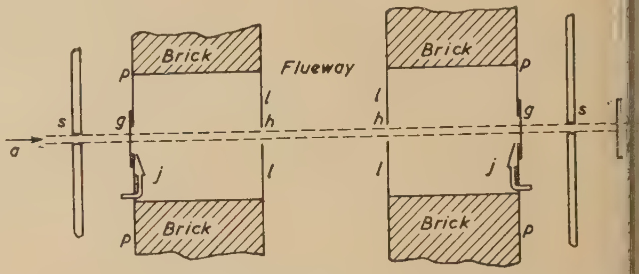


Fig. 2. Vertical section through chimney showing air jets and windows

traverses the smoke in the flue-way and falls on the pho electric cell *P*. The components are fixed in position in su a way that expansion of the stainless steel lining during te does not interfere with the pencil of light. An air-jet flattened into the shape of a fish-tail, is arranged to direct stream of air over the inner surface of each window *g*. T jet is connected to an external source of compressed a through a drying column. These arrangements are based a design due to Wey(17) and prevent the glass windows fro becoming smoked. The equipment has been used co tinuously week after week without any sign of a deposit an is preferred to the heated window system described Ockelford.(28)

2.24 *The light-guide.* A light-guide *L* (Fig. 1), ma from a single sheet of Perspex, $\frac{1}{2}$ in. thick, directs the lig round the outside of the chimney by internal reflexion at th polished surfaces. The pencil of light *b*, which enters th guide, is not strictly parallel, and consequently, after numero reflexions within the guide, the emergent beam is somewh diffuse. The photoelectric cell is therefore placed very clo to the face of the guide in order to collect the total ligh transmitted. The critical angle for total internal reflexio within Perspex is approximately 42° at wavelengths withi the visible spectrum so that some light is lost at each reflexio as the angle of incidence is 45°. It was found, during develop ment, that deposition of dust on the outside surface of th Perspex appreciably affected the amount of light reflecte internally. Thus all the lateral surfaces are loosely wrappe with aluminium foil and the aluminium foil covered wit crepe latex. This increases the transmission of light throug the guide and also prevents dust settling on the Perspe surfaces. It is worthy of note that several guides we constructed with smooth bends from solid Perspex rod c circular section. Theoretically, these should have been satis factory with total internal reflexion at each bend. In practice much light was lost at the bend and no satisfactory explanatio has been found for this failure.

2.25 *The photoelectric cell.* A selenium barrier-laye type cell is used which requires no external power suppl It is partially enclosed in a housing and leads to the amplifie are screened against electromagnetic pickup. By virtue o ie design of the instrument, it is not necessary to control ie temperature of the cell, although the housing gives some otection against sudden draughts. As already explained, ie sensitive area of the cell must be brought close to the nd of the light-guide. This is not possible with most types photoemissive cells because of the glass envelope surounding the sensitive area. The barrier-layer cell appears work satisfactorily and shows no hysteresis or fatigue fects when used continuously over periods of weeks. The ehaviour of a barrier-layer photoelectric cell in a.c. circuits as been discussed by Sargrove(29) and this probably applies its operation in this instrument.

2.26 *The amplifier and balancing motor.* The amplifier nd the balancing motor are units taken from a Brown lectronik Potentiometer. The motor is a two-phase inducon motor with four poles per phase, designed to withstand echanical stalling under full power without excessive eating. The a.c. signal is applied directly to the input ansformer of the amplifier. The impedance of this transrmer is 400 Ω if half the primary is used and 1600 Ω if e whole winding is used. By using only half the primary, e load on the photoelectric cell is reduced and the response aracteristic of the cell is rectilinear; the dead zone of the mplifier (minimum input which will cause the motor to urn) is 7×10^{-6} V compared with 14×10^{-6} V if the hole winding is in use.

The amplifier operates in two stages, voltage amplification nd power amplification, the former providing sufficient gain drive the latter. For satisfactory operation, the input gnal from the photoelectric cell must be in phase with the upply voltage to the amplifier and balancing motor, since ny out-of-balance signal will tend to block the voltage mplification and reduce the motor speed. In fact, if the nput signal is $\pi/2$ out of phase with the supply, the amplifier ill be completely blocked and the motor will not turn. The hase of the input signal is fixed by the position of the chopper lade on the spindle of the synchronous motor and this osition is chosen to give the best performance. During the itial development of the instrument, the phases of the input gnal and of the mains supply were compared with a cathodeay oscilloscope and the position chosen accordingly. It has een found to be much simpler to find the "out-of-phase" osition of the chopper blade when the balancing motor will ot turn and then to rotate the chopper blade on the spindle rough $\pi/4$. A detailed description of the amplifier circuits given by Gibson and Terry.(30)

2.27 *The optical wedge.* The balancing motor is geared a wire drive to which is attached a carriage holding the ptical wedge. The carriage has a ball-bearing movement long a horizontal rail and the wire attachment to the carriage spring-loaded, there being no backlash or slip. The optical edge moves horizontally across and normal to the pencil of ght *b*. It is placed just before the entrance to the light uide and can move a distance of almost 12 in. An assortent of interchangeable wedges, each 12 in. long, is available r use; the optical density of each varies linearly with length, nd a wedge is chosen for use according to the blackness of moke to be expected. Each wedge has the final $\frac{1}{2}$ in. at the ark end completely blackened out to act as an optical buffer hould the smoke be blacker than anticipated and this revents the balancing motor from straining against the stop t the end of its traverse. Each wedge consists of a thin prism f transparent gelatine containing colloidal carbon in suspension, and is shaped as a tapering wedge by being cast etween two slabs of optically worked glass.(31) The linear elationship between optical density and length is extremely accurate as may be seen from a typical calibration (Fig. 3). An assortment of wedges of gradients between 0·032/in. and 0·193/in. over a usable length of 10 in. is available.

Since the pencil of light covers an area of the wedge $\frac{1}{2}$ in. wide, the optical density value at the balanced position is the mean value over this length of wedge, which, for a linear wedge, is at the mid-point. By this means, even if any small irregularities in the linearity of the density gradation occur, they are smoothed out.

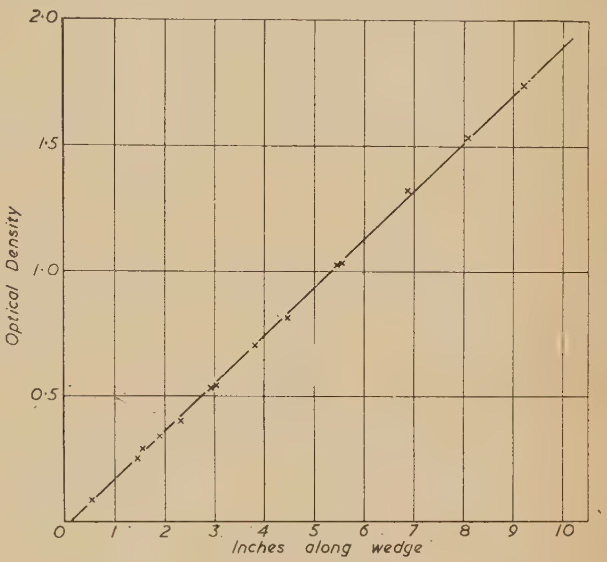


Fig. 3. Calibration of wedge No. 6545

2.28 *The transducer and recorder.* The wire drive also engages a pulley on a transducer, two and a half turns of wire being used as a precaution against slipping. The transducer is connected to an electronic pen recorder in a bridge circuit and the recorder accurately follows its movements. The recorder has a $3\frac{1}{2}$ s full-scale movement over an 11 in. chart, and a selection of chart speeds from 2 to 12 in./h can be used. This method has the advantage that the recorder can be located at any distance from the chimney as desired.

2.29 *The light trimmer.* Any one of the optical wedges not in use for measurements is used as a light trimmer. A trimmer is necessary to equalize the illumination of the two pencils of light when there is no smoke in the flue-way, and to adjust the zero position of the optical wedge as required.

3. PERFORMANCE

3.1 *Resolution*

The resolution of the recorder, in terms of its trace width, is of the order of 0·3% of full-scale movement. The ultimate sensitivity of the measurement is the minimum change of density value which will just move the balancing motor with the particular amplifier—this value is within the resolution of the recorder.

3.2 *Speed of response*

The time taken by the balancing motor to move the wedge from one balanced position to another is a matter of considerable importance. The relationship between the speed of the motor and the input voltage to the amplifier is shown in Fig. 4, for a load torque on the motor of less than 2 oz in. Fig. 4 shows that the motor cannot turn until the input to the amplifier exceeds 7×10^{-6} V; the motor speed then increases rapidly for a small increase in the voltage and approaches the top speed at 50×10^{-6} V. As a result, the speed of response is not constant along any one wedge nor from wedge to wedge.

Movement from end to end of each wedge in either direction takes $4\frac{1}{2}$ s and with most of the wedges an intermediate balanced position is attained in less time. However, with the wedges of low density gradient, movement between intermediate balanced positions can take up to 7 s. This anomaly arises because the linear distance between points of given density is greater and also because the balancing motor does not attain maximum forward speed before retardation begins.

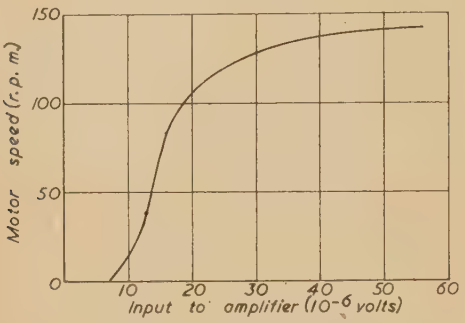


Fig. 4. Characteristic of balancing motor

Experience with the use of the instrument has shown that the speed of response is more than sufficient to allow it to follow changes in the smoke emission from domestic heating equipment.

3.3 *Spectral response*

The light source is a tungsten filament lamp giving white light. The density wedges are neutral with a constant absorption from 460 to 640 mμ(31) and the Perspex light guide is neutral from 400 to 800 mμ.(32) The spectral response of the selium barrier-layer cell(33) has its maximum response at 580 mμ which is close to that of the peak sensitivity of the human eye, which is set at 550 mμ. The cell is sensitive over the whole visual range and extends slightly beyond both on the blue and the red end, but in this class of application it can be considered to respond in the same general way as the eye.

3.4 *Calibration of the wedges*

The optical density of a neutral filter is not completely independent of the optical system in which it is used and is greater for parallel than for diffuse light.(31) The wedges were therefore calibrated in position in the instrument by using neutral density plates in the chimney. The plates were previously calibrated with a photometer using parallel light and a photoelectric cell of known characteristic, the light source and cell being spare components for the instrument, thus ensuring that the conditions of spectral response were the same. The density measured is the B.S. Specular Density.(34)

3.5 *Summary*

The instrument is warmed up and ready to operate within 2 min of being switched on. Optical density measurements are possible within a series of ranges from 0–0·35 and 0–2·0 over a linear scale of length 10 in. The resolution is within 0·3% of full scale over all ranges and the response time less than $4\frac{1}{2}$ s under normal conditions. The density measu
is that seen by the human eye.

The performance is independent of variations in the sup
mains and has been tested for surges within the range
and 250 V a.c. One instrument has been in use for o
three years, and at times has been used continuously
several weeks, the only replacements have been a few la
bulbs.

Zero drift is inconsequential, provided that an adequ
supply of compressed air is maintained to keep the f
windows clean; 5 ft^3/h per window is sufficient and
dilution of the smoke by this air is negligible considering
chimney flow is often over 10 000 ft^3/h.

General view of the instrument *in situ* are shown in Fi
5 and 6.

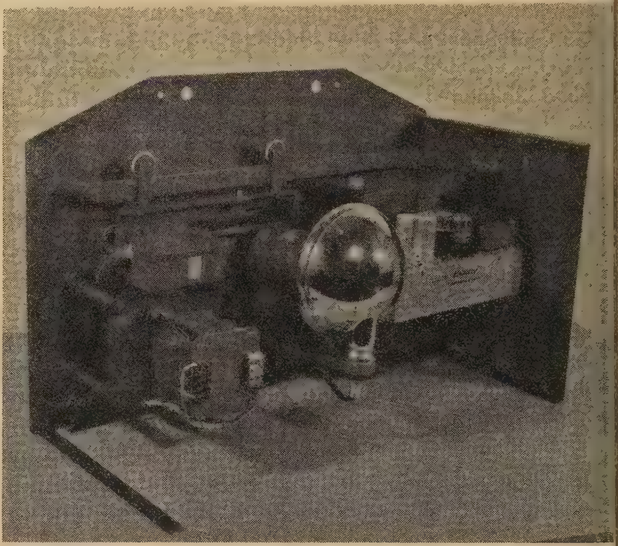


Fig. 5. General view of the instrument with cove
removed

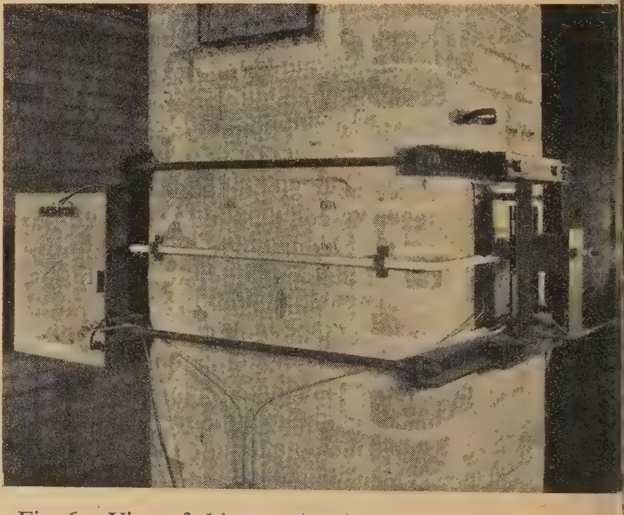


Fig. 6. View of chimney showing instrument in position

ACKNOWLEDGEMENTS

The instrument described was developed as part of t
programme of the Fuel Research Board of the Departme

f Scientific and Industrial Research and is published by ermission of the Director of Fuel Research. The illustrations re Crown Copyright and are reproduced by permission of e Controller, H.M. Stationery Office.

REFERENCES

(1) Fahrenbach, W. *Forsch. IngWes.*, **2**, p. 395 (1931).
(2) Zimmermann, E. *Ver. dtsch. Ing. Z.*, **75**, p. 481 (1931).
(3) Locklin, D. W., and Parmelee, G. V. *Heat. Pip. Air Condit.*, **22**, p. 107 (Nov. 1950).
(4) Tasker, C. *Heat. Vent. Engr*, **25**, p. 52 (1951).
(5) Blackie, A., and Bruckshaw, J. M. *J. Inst. Fuel*, **12**, p. 24 (1938).
(6) Shaw, W. F. B., Hurley, T. F., and Fox, L. L. *Heat. Vent. Engr*, **25**, p. 494 (1952).
(7) Rowse, R. H. *J. Inst. Fuel*, **22**, p. 47 (1948).
(8) Sawford, F. *Mech. Engng*, **49**, p. 999 (1927).
(9) Griffin, V. P., and Briesky, J. V. *Mech. Engng*, **51**, p. 984 (1929).
10) Krönert, J. *Arch. Tech. Messen*, T5 (1931).
11) Bean, R. D. *J. Sci. Instrum.*, **9**, p. 391 (1932).
12) Hill, A. S. G. *J. Sci. Instrum.*, **14**, p. 296 (1937).
13) *U.S. Bur. Mines Bull.*, **404**, p. 51 (1937).
14) Brown, K. M. *Soc. Automot. Engrs, J.*, **48**, p. 188 (1941).
(15) Schweitzer, P. H. *Instruments*, **15**, p. 346 (1942).
(16) Eldred, D. *Power*, **93**, p. 78 (1949).
(17) Wey, R. J. *Engineer*, **282**, p. 283 *et sub.* (1942).
(18) Foy, C. J. *Instruments*, **25**, p. 763 (1952).
(19) Grieve, T. W., and Rowell, G. M. *Coal Res.*, **6**, p. 86 (1946).
(20) Hales, J. S. *Fuel*, **19**, p. 231 (1940).
(21) Bredl, J., and Marsden, K. J. *B.C.U.R.A. Inf. Circ.*, 29 (1950).
(22) Dobson, G. M. B. *Proc. Roy. Soc. A*, **104**, p. 248 (1923).
(23) Toy, F. C. *J. Sci. Instrum.*, **4**, p. 369 (1927).
(24) Hardy, A. C. *J. Opt. Soc. Amer.*, **19**, p. 96 (1929).
(25) Hill, A. S. G. *Trans Faraday Soc.*, **32**, p. 1125 (1936).
(26) Schoen, J. *Arch. Tech. Messen* T25 (1950).
(27) Wooster, W. A. *J. Sci. Instrum.*, **32**, p. 457 (1955).
(28) Ockelford, C. W. *J. Sci. Instrum.*, **15**, p. 190 (1938).
(29) Sargrove, J. A. *J. Brit. Instn Radio Engrs*, **7**, p. 86 (1947).
(30) Gibson, V. D., and Terry, R. A. *Minneapolis-Honeywell Reg. Co. Phil. Bull.* No. B 15–12.
(31) *Ilford Colour Filters.* Ilford Ltd., Ilford.
(32) *Perspex Acrylic Materials.* I.C.I., Welwyn Garden City.
(33) Houstoun, R. A. *Phil. Mag.*, **33**, p. 226 (1942).
(34) Brit. Stand. 1384: 1947.

A mechanical Gardner mobilometer

By J. E. Roberts, B.Sc., A.Inst.P., A. J. Taylor and D. E. Woods, B.Sc., Ph.D., F.R.I.C., M.I.Chem.E.,
Armament Research and Development Establishment, Fort Halstead, Kent

[*Paper first received* 25 *May, and in final form* 13 *September*, 1956]

A mechanical counterpart of the Gardner mobilometer is described which gives results in agreement with those obtained on the hand-operated instrument and enables the rate of testing to be increased to sixteen determinations per hour.

The Gardner mobilometer used for measuring the consistency of paints, oils and greases is a hand-operated instrument. In order to ensure repeatability and reproducibility of test results he instrument is accurately dimensioned and a carefully egulated test routine is stipulated. A satisfactory routine is described below.

The mobilometer is assembled and adjusted in the working position until the plunger rod and Gardner tube are vertical (Fig. 1). The plunger is forced manually down through the fluid to be tested until the disk touches the bottom of the ube, and then withdrawn until the lowest mark *C* on the rod just shows above the bearing. This double stroke is carried out in a period of not more than 10 s (care must be aken not to allow fluid to be carried into the bearing). After working the sample, the plunger rod is held at the bearing and suitable weights placed on the pan. The interval between he end of the working stroke and the start of the first run must be 60 ± 10 s. The timing run is started by releasing he weighted plunger assembly and the time interval, between he passing of the two marks *A* and *B* (on the plunger rod) past the upper surface of the bearing, is recorded. Next, he weights are removed from the pan, and the two working strokes repeated within a period of 10 s. The above procedure is then repeated with four different loads chosen so hat the times of fall bracket 100 s and are within the range 50 to 150 s. The time between runs is maintained at 60 ± 10 s and the test carried out at 25 ± 0·5° C. The load in grammes equired to give a time of fall of 100 s is obtained by linear interpolation from the graph log (load) against log (time of fall). In the graphical treatment the best straight line is drawn through the experimentally determined points, any obviously discordant results being repeated. A duplicate determination is carried out and the two values of the "100 s load" should not differ by more than 10% or the test is repeated. The mean of the two results is taken as the 100 s Gardner value of the material.

The result of adopting this somewhat complicated routine is that the average rate of carrying out determinations generally does not exceed about six per hour. It was decided to design a direct-reading instrument on which the Gardner consistency would be shown on a dial gauge, in order to eliminate much of the personal error inherent in the use of the hand instrument and also to increase the number of determinations which could be carried out in a given time.

THE MECHANICAL INSTRUMENT

The basic design of the instrument was agreed in conjunction with Paine Engineering Developments Ltd., Fernhurst, Surrey. The Gardner tube containing the test sample is mounted on a platform which is driven upwards at a constant velocity, while the plunger assembly inside it transmits the thrust to a leaf spring which activates a jewelled dial gauge. This method was adopted as the movement is small and therefore the speed of the cylinder relative to the plunger quickly reaches the nominal figure. The maximum movement of the leaf spring is 0·050 in.

12% and 15% ru

1st reversal. Time from start (s)

		30–40		40–50		50–60		60–70		70–80		80–90	
Solution	*Concentration (%)*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	
A	12	530	2	535	3	525	7	520	Nil	520	2	—	—
B	15	1210	20	1240	15	1245	Nil	1245	Nil	1250	3	—	—
C	12	340	Nil	340	Nil	340	Nil	340	Nil	340	Nil	340	N
D	15	705	3	720	10	740	3	740	Nil	735	3	740	

C = consistency

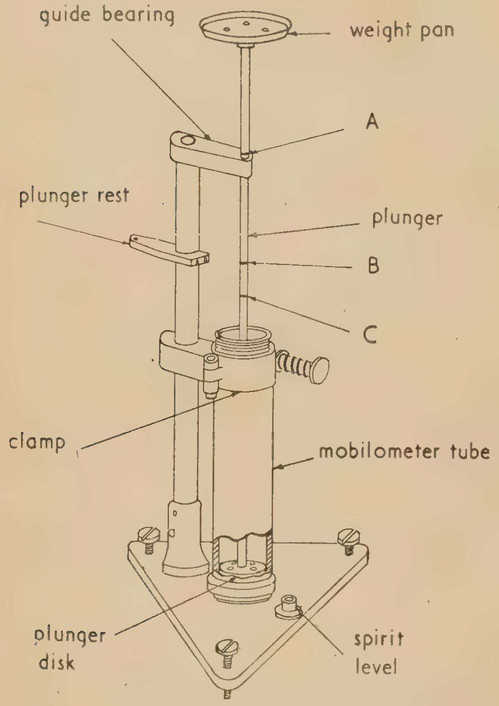

guide bearing
weight pan
A
plunger rest
plunger
B
C
clamp
mobilometer tube
plunger disk
spirit level

Fig. 1. Hand-operated Gardner mobilometer

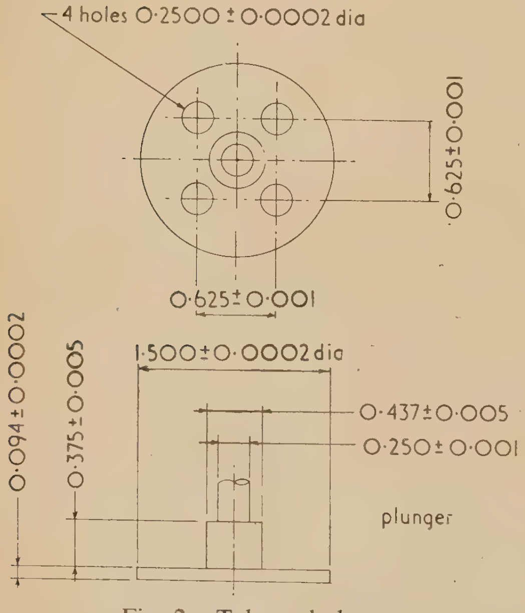

4 holes 0·2500 ± 0·0002 dia
0·625±0·001
0·625±0·001
1·500±0·0002 dia
0·437±0·005
0·250±0·001
plunger
0·094±0·0002
0·375±0·005

Fig. 2. Tube and plunger

Tube bore equals 1·539 ± 0·002 in. diameter before plating. Permissible ovality 0·002 in. Thickness of chromium plating 0·0005 in.

All measurements are in inches.

If the instrument had been based on a normal ha operated Gardner tube it would have been necessary accommodate in a vertical plane about 20 cm of plun 24 cm of tube and 20 cm of platform column. Moreove single reversal operation (i.e. the tube raised at a const rate of 0·1 cm/s until the plunger disk was within 1 cm the base of the tube, the motion reversed, and the t lowered to its original position) would have occupied ab 400 s. From preliminary experiments on thrust and posit of the plunger in the tube, it was found that the effe length of the fluid column could be reduced to 12·5 without any change in the thrust recorded on the dial gau This modification brought about a three-fold reduction in total height of the relevant portions of the instrument a

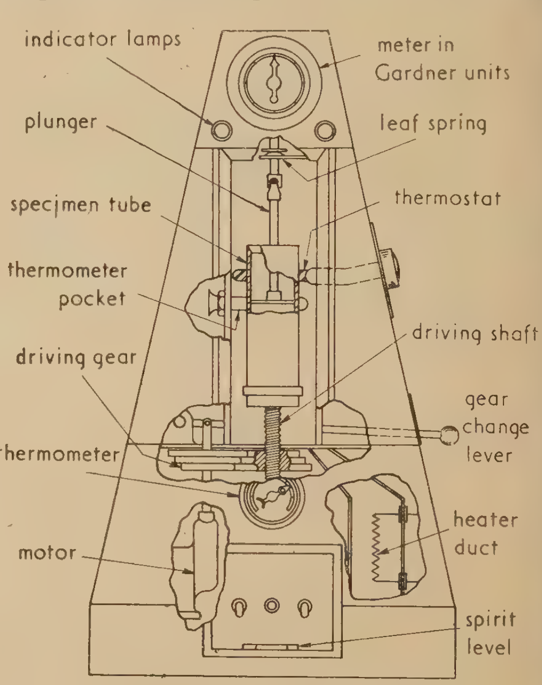

indicator lamps
meter in Gardner units
plunger
leaf spring
specimen tube
thermostat
thermometer pocket
driving shaft
driving gear
gear change lever
thermometer
heater duct
motor
spirit level

Fig. 3. Mechanical Gardner mobilometer

reduced the time for a single reversal operation to abo 200 s. Subsequently, this time was reduced to about 120 by arresting the upward travel of the tube when the plung disk was about 2½ cm from the base of the tube, and al increasing the speed of return by the use of a high gear.

At a set distance of stroke, indicator lamps light a remain on for 1 cm of stroke. This indication of when t reading should be taken has been found necessary as th motion of the fluid through the holes is irregular, and ma fests itself as an increasing Gardner value as the plung approaches the base of the tube. The explanation of this h been shown by film records of the motion of viscoelast fluids. The motion of particles suspended in the fluid h been observed, using a glass Gardner tube and a high spee ciné camera. The motion of the fluid is such that only o *lutions in hydrocarbons*

2nd reversal. Time from start (s)

30–40		40–50		50–60		60–70		70–80		80–90		100 *s Hand Gardner value (g)*
C	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	
480	12	505	3	505	3	505	2	505	Nil	—	—	525
940	17	1180	17	1215	7	1230	3	1245	3	—	—	1215
315	3	325	3	330	Nil	330	Nil	330	Nil	325	Nil	325
640	30	690	7	700	Nil	705	3	710	Nil	715	3	710

S = the maximum deviation from mean readings

f the holes is in full use at a time so that there is a cross otion of fluid between the holes, and, in general, a back ow of the fluid takes place through one hole. When the lunger approaches the base of the tube this motion is artially stopped so that the fluid's choice of the easiest path restricted.

The instrument is shown in Fig. 3. The accurately dimenoned parts involved in the consistency determination omprise a highly polished, chromium-plated brass tube and ur-hole disk (plunger) of which the dimensions are given in ig. 2. End caps are supplied for the tubes so that little loss f solvent takes place during storage. Before a tube is laced in the instrument for a determination, one end cap is emoved and replaced by a guide-ring which ensures safe ntry of the disk into the tube. The plunger rod is held by universal coupling to a leaf spring and the Gardner tube is ounted on a platform by means of a bayonet fixing. The latform is carried on a vertical threaded rod which can be oved at uniform rates by means of a synchronous motor cting through a train of gears. The gearbox enables speeds f 0·4, 0·1 or 0·025 cm/s to be chosen, since with some uids measurement at three different rates of shear is dvantageous.

Some types of fluid tend to set up flickering of the dial auge caused by an interchange of energy between the spring nd the liquid. This interchange of energy has been minized by the addition of two dashpots fitted to the leaf spring. hese are so constructed that the degree of damping increases ith increasing Gardner values; hence the spring quickly eturns to zero. The indicator lights below the dial gauge how when the reading should be taken. The instrument is fitted with a heater which is thermostatically controlled so that air at a constant temperature (±1° C) passes round the Gardner tube. This is necessary as, although the main body of a gel takes some time to heat or cool appreciably, a thin layer near the tube wall assumes the tube temperature fairly quickly and the absence of a heater would give rise to inaccuracies in the Gardner determination. Three levelling screws and a bubble level indicator are provided.

PERFORMANCE

The readings given by the mechanical Gardner instrument were compared with those obtained on the hand-operated Gardner mobilometer, using as test compositions various gels of metallic soaps in hydrocarbon media and also 12% and 15% solutions of rubber in hydrocarbon. The results on the latter are given in the table. In all cases it was found that, in order to obtain numerical readings in satisfactory agreement with those obtained with the hand instrument:

(*a*) the tube must be given a complete up and down working stroke, which may be done in the high gear, prior to the determination, and

(*b*) the dial gauge reading, when examining soap gels, should not be taken until at least 7 cm have elapsed from the start of the upward travel of the tube.

As a result of (*b*), it has been arranged, as mentioned earlier, that the indicator lights are illuminated over the range of travel of the tube 7 to 8 cm from the start.

Owing to the fact that two complete reversals are necessary for each determination the rate of working has been found to be about sixteen determinations per hour.

The generation of accurate cylinders

By D. A. Davies, B.Sc., Division of Industrial Chemistry, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia

[*Paper received* 3 *July*, 1956]

A method of diamond-turning accurate cylinders for the production of helical rulings is described. Details are given of the special tool holder, and performance figures quoted show that, for a typical cylinder, the central half may be held constant in diameter to ±10μ in.

n the preparation of rulings by the Merton(1) method, it is ecessary to prepare mandrels having a mirror finish and of niform diameter. It has been found possible to diamondurn brass bars of about $1\frac{1}{8}$ in. diameter, parallel to ±10 μin. ver a 10 in. length in the centre of a 17 in. bar, using only special tool holder, an ordinary tool-room lathe and a aceted diamond tool similar to B.S.S. 1148: 1943.

The method(2) is based on the fact that, given homogeneous aterial, a lathe cannot turn a bent bar though it may turn ne which is barrel shaped or waisted. If then a cutting tool e attached to and guided by the mandrel itself by means of an elastic bearing, then it must be at a fixed radius from the centre of the mandrel, provided that the bearing has radially symmetrical elastic properties. Simultaneous rotation of the mandrel and translation of the tool bearing assembly along it must generate a uniform cylinder, provided that the cutting forces are small relative to the centring forces of the bearing, and that temperatures remain constant. In practice, friction forces do cause a rise in temperature and it becomes worthwhile to use a copious flow of cutting oil and to reduce friction by using a Michell type bearing.

Fig. 1 shows an isometric view of the self-centring tool holder. The bearing housing is split into halves for easy assembly on, and removal from, the mandrel. It carries three bearing pads, 3½ in. long, disposed at 120° about the axis of the bearing. Each pad is of steel, faced with $\frac{1}{16}$ in. neoprene, and can tilt about the rocker pin to promote the formation of an oil wedge. The bearing is relieved in the neighbourhood of the diamond tool to facilitate chip removal, and with the neoprene scraper complete removal is possible. The lower half of the housing carries the diamond tool in a micrometer-adjusted holder.

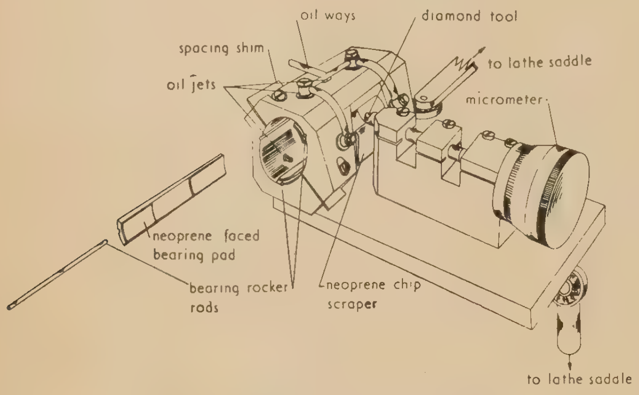


Fig. 1. Self-centring tool holder

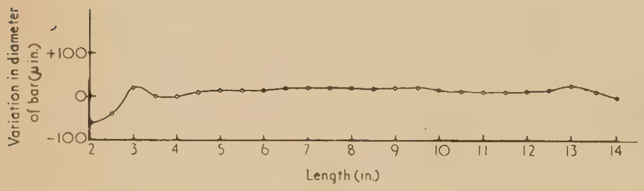


Fig. 2. Diameter variation of a typical bar

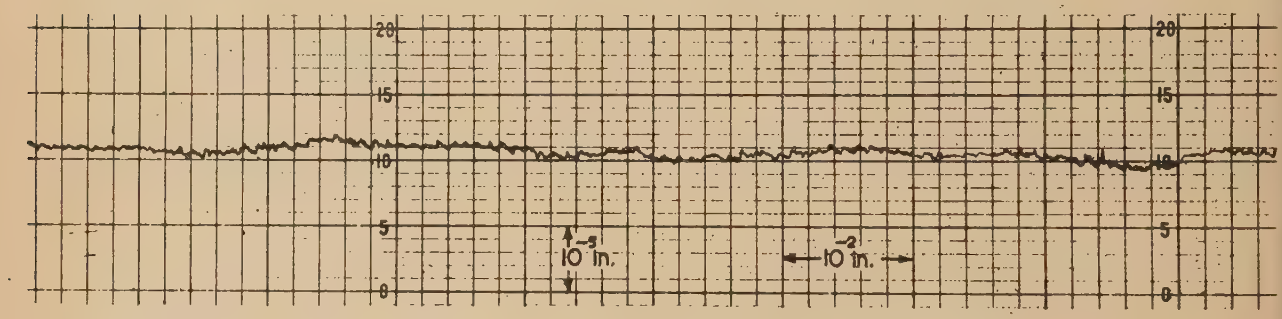


Fig. 3. Talysurf record of surface finish

In use, the bearing is adjusted by addition or removal of shims so that with a stationary mandrel between centres on the lathe the bearing is quite free to rotate, and when th lathe is rotated there is no perceptible rise in torque. Tran lation is effected *via* the saddle of the lathe by two push-ro terminating in ball races. One is located underneath the to holder to prevent rotation and the other is placed as near possible to the mandrel itself.

It is not possible to turn to within 1½ in. of the end of th bar and it is desirable to make the ends as close as possib to the finished size for the centre of the bar. In this wa the discontinuity caused when the bearing pads pass over step in the bar can be minimized. Better results are obtaine if two or more light cuts of 0·0001–0·0002 in. are take Fig. 2 shows a diameter plot of a typical bar.

Fig. 3 shows a Taylor–Hobson Talysurf record of th surface finish on the same bar in which the surface roughnes expressed as centre line average, is less than ±1 μin. with waviness in surface of approximately 0·03 in. pitch amountin to ±1 μin. It is clear that a simple inversion of the meth will make it applicable to the production of cylindrical hole

Another possibility arises from the observation that th neoprene lined bearing will behave as a Merton nut.(3) then a mandrel is ruled with a primary helix of corre average pitch the tool may be used to recut it with a hel of uniform diameter whilst averaging out the periodic erro of the primary ruling.

This process has been developed specifically for diffractio grating production but it will be apparent that it may b adapted for more general workshop use.

The author wishes to thank Mr. J. Stiff for constructio work and collaboration throughout this project, and M K. C. Lang, Defence Research Laboratories, Maribyrno for surface finish measurements.

REFERENCES

(1) Merton, Sir Thomas. *Proc. Roy. Soc. A*, **201**, p. 18 (1950).
(2) Australian Patent Application No. 19298/56.
(3) Hall, R. G. N., and Sayce, L. A. *Proc. Roy. Soc. A* **215**, p. 536 (1952).

Laboratory and workshop notes

The magnifying powers of optical instruments

By D. A. Richards, M.Sc., A.R.C.S., Physics Department, University College of Wales, Aberystwyth

[*Note received* 9 *March*, 1956]

Ieasurements of the magnifying powers of optical systems ntail the comparison of the angle subtended at the eye by ne object and by the image. Where the optical system gives ise to a virtual image a measurement of the magnifying ower, if it could be made rapidly and accurately, would fford a satisfactory method of determining the optical onstants of the system. A case in point is the determination f the magnifying power of a telescope. In the elementary iboratory the comparison of the two angles is usually made y viewing the object through the telescope with one eye and irectly with the unaided eye. The method is far from ccurate. Some practical physics text books suggest that a ondition of no parallax should be sought, as though the wo eyeballs were rigidly interconnected.

The use of the double-mirror device, described below, gives ise to beams of light at a fixed angle apart, permitting monoular vision and increasing, very considerably, the accuracy f measurements of the magnifying powers of optical systems.

The double mirrors are shown in Fig. 1. Two partiallyilvered glass plates, inclined at a small angle, are clamped ogether, the silvered faces being innermost. In the form onstructed for use in this laboratory, the plates, which had transmission coefficient of 16%, were 1 × ½ in., in contact t their upper edges, while a short length of No. 24 s.w.g. wire eparated the lower edges. The whole assembly was mounted ver a hole ½ in. diameter in a brass plate. The angle between uccessive images was about 0·044 rad, or 2·5°.

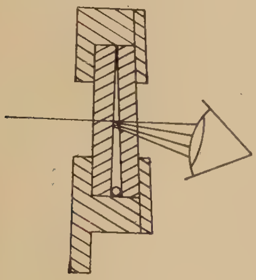


Fig. 1. Section through the double-mirror device

On viewing a bright point source of light through the double nirrors, multiple images of the source are seen by the eye. The angle between successive images is twice the angle between he mirrors, irrespective of the angle of incidence. The listances from the double mirror to the source of light and o its successive images are sensibly constant provided that he thickness of the air space between the mirrors is always mall.

The method of measuring the magnifying power of a elescope, using the double mirrors, is shown in Fig. 2. A orizontal slit in a vertical paper scale is illuminated from ehind by a straight filament lamp. The telescope, mounted orizontally, is set at a suitable distance from the scale and ocused on the slit, the eyepiece having previously been ocused on the crosswire to give an image either at infinity r 25 cm. The double mirror is held in a clamp in the usual ye position. On looking through the double mirrors and elescope, four or five images of the illuminated slit are seen, uperposed on the direct image of the scale, either above or below the slit. It is, of course, necessary to adjust the height of the lamp filament to be on the line of sight determined by the slit and the centre of the telescope objective. Multiple images of the scale also occur, but these are faint compared with the direct image of the scale and the multiple images of the slit. If α is the angle between the multiply-reflected beams, D the distance from the eye to the scale, x the apparent distance from the slit to the first reflected image of the slit, then the magnifying power is $\alpha D/x$.

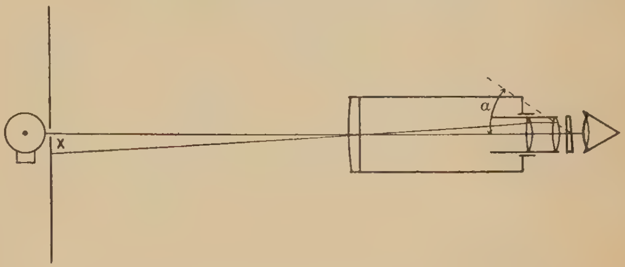


Fig. 2. The double-mirror device used in the determination of the magnifying power of a telescope

The angle α can be determined using a spectrometer, or by viewing the scale directly through the double mirror. Since the co-incidence of the multiple images of the slit and the direct readings of the scale is unaffected by any optical system between the eye and the double mirrors, the multiple images can be viewed by a telescope placed with its object glass close to the double mirrors, thus enhancing the accuracy of the scale readings.

This has been a routine experiment in the teaching laboratory of this College for a number of years. The variation of magnifying power with object distance and with image distance can readily be determined.

The magnifying power of a microscope is determined by placing the double mirrors in the normal eye position. A transparent engraved scale is placed on the microscope stage and illuminated from below. The apparent length of the scale image that subtends an angle α is determined, and, knowing α, the magnifying power of the microscope may be calculated. The determination is somewhat easier if it can be arranged to illuminate one of the fiducial marks of the scale more brightly than the rest.

Various types of focometer have been described from time to time.* Fig. 3 shows how the double mirrors may be used in a focometer for the rapid determination of the focal length of thin concave or convex lenses. The double mirror M is fixed at a distance d above a platform L provided with a

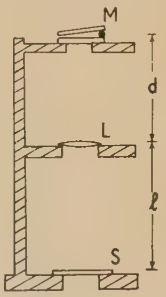


Fig. 3. The double-mirror device used in a focometer

diaphragm over which lies the lens under test. At a distance l below L is a transparent scale S illuminated from below. It can be shown that the overlap of the image of the scale viewed directly and the first reflected image is $[l + d - (ld/f)]\alpha$, where f is the focal length of the lens, assumed positive for a convex lens. As with the two previous applications, one of the fiducial marks of the scale can be illuminated more brightly than the rest. If so desired the scale may be calibrated directly in focal lengths, both positive and negative, for fixed values of d and l. For certain focal lengths the image of the scale may lie outside the range of vision of the eye. In these cases, the image of the scale may be observed with an auxiliary lens between the eye and the double mirrors, since, as in the case of the telescope experiment described above, this does not affect the coincidence of the direct image and the multiply reflected images. If the distances l and d of the focometer are made variable then the instrument becomes an optical bench. The double mirror may therefore be used on the optical bench and is most useful in dealing with virtual images.

---

* Martin, L. C. *Optical Measuring Instruments*, p. 188 (London: Blackie and Sons Ltd., 1924).

It must be noted that the multiply-reflected beams are not strictly concurrent. On tracing a ray through the double mirror, it will be seen that the direct ray and the first reflected ray intersect on the incident side at a distance of the order of the path of the direct ray between the mirrors. This is a very small distance provided the angle between the mirrors is small and sighting of the multiply reflected beams is done near the line of contact of the mirrors. The intersections will generally be in the glass of one of the plates and account must be taken of the optical as distinct from the geometrical distance in optical bench experiments.

The adaption of a metallurgical microscope to the "light profile" method

By H. Mykura, B.Sc., Ph.D.,* University College of the West Indies, Jamaica, British West Indies

[*Note received* 23 *May*, 1956]

The "light profile" method for microscopic surface topography measurement developed by Tolansky(1,2) uses an obliquely incident illuminating beam to throw an image of a fine wire on the specimen surface. Changes in specimen height are then shown up as lateral shifts in the wire image. The optical system as used by Tolansky is shown diagrammatically in Fig. 1(*a*); a solid reflecting sector (fitted in the Vickers projection microscope system) provides the oblique beam. With a microscope which has only the usual half-silvered glass reflector for incident light illumination, the simple adaptor shown in Fig. 1(*b*) enables the light profile technique to be used. In this the ordinary field and aperture stops, lamp and lens are replaced by an oblique stop placed as close to the half-silvered reflector as possible and a field stop (on which the fine wire or wires are mounted) so placed that the image produced by the objective is in focus on the specimen surface. Monochromatic light has to be used to eliminate the chromatic aberration caused by the oblique passage of the illuminating beam through the objective. This is provided by a separate high pressure mercury vapour lamp and filter.

A means of rotating the direction of the profile on the specimen is also required, in order to bring the shadow of the wire perpendicular to any desired feature (e.g. scratch or groove). If the microscope is not fitted with a rotating stage, this is accomplished by clamping the oblique stop to the fiel stop and rotating them together (Fig. 2). In some mic scopes the illuminating system and half-silvered mirror ca rotate about the microscope axis, and such rotation provid the same adjustment, but this means that the lamp must re-alined after every rotation.

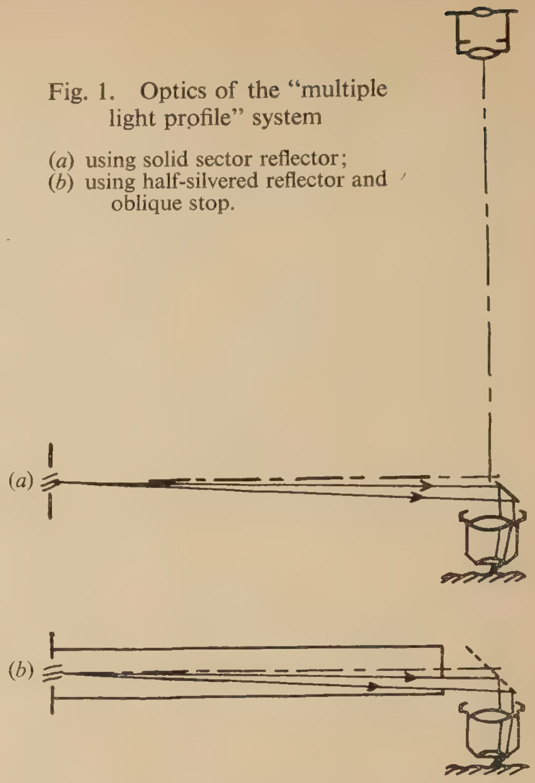


Fig. 1. Optics of the "multiple light profile" system

(*a*) using solid sector reflector;
(*b*) using half-silvered reflector and oblique stop.

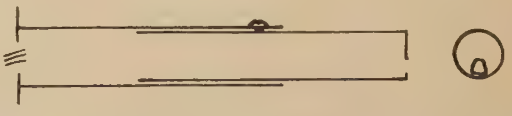


Fig. 2. The adaptor built to allow focusing of the wires on the object and simultaneous rotation of wires and oblique stop

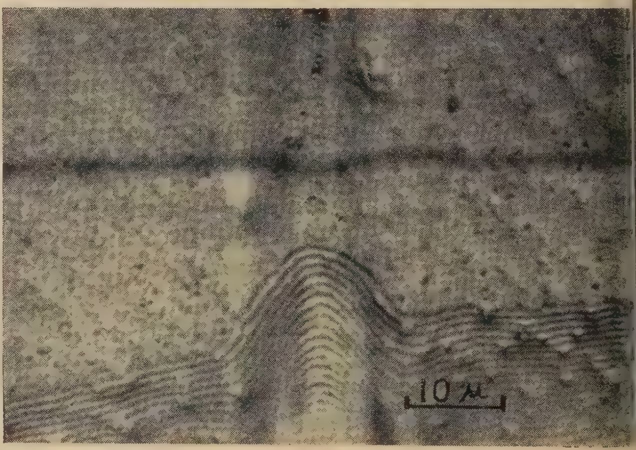


Fig. 3. Combined interferogram and light profile of a groove. Taken through n.a. 0·85 objective. Fringe contour interval $\lambda/2n = 0\cdot18\ \mu$; light profile ratio $R = 0\cdot85$

---

* Now at Department of Natural Philosophy, University of Glasgow.

The ratio of depth to lateral magnification ($R = M'/M$) epends on the numerical aperture of the objective and the position of the oblique stop. It is best determined for each objective by calibration with a known object which has been hecked interferometrically.[2] With lenses of n.a. 0·85 or greater, values of R between 1·0 and 1·2 can easily be obtained. Fig. 3 shows a light profile ($R = 0{\cdot}85$) and an nterferogram (using the oil-drop technique)[3] at adjacent points of a groove. This was taken with an n.a. 0·85 objective and illumination adjusted to give reasonable fringes as well as the light profile; somewhat better profiles can be obtained, particularly when an oil immersion objective is used. The nterference technique is seen to be much more sensitive and accurate. However, the light profile is simpler to use and can deal more easily with larger and discontinuous changes n light, so it should find a number of applications.

REFERENCES

1) Tolansky, S. *Nature* [*London*], **169**, p. 445 (1952).
2) Tolansky, S. *Properties of Metallic Surfaces*, p. 12 (London: Institute of Metals, 1953).
3) Tolansky, S., and Omar, M. *Nature* [*London*], **170**, p. 81 (1952).

A note on joining tungsten wire to other metals

By K. F. Chackett, B.Sc., Ph.D.,* P. Reasbeck, B.Sc., Ph.D.,* and D. G. Tuck, B.Sc., Ph.D.,† Londonderry Laboratory for Radiochemistry, University of Durham

[*Note received* 1 *June*, 1956]

Tungsten is widely used in glass vacuum systems and similar apparatus because of the ease with which it can be sealed nto Pyrex glass, so that a method for making good electrical connexion with the more common metals is desirable. The echnique described below is especially useful for very fine tungsten wire, or where spot-welding is difficult; it has been used by us in the construction of Pirani gauges for micro-gas analysis. Recent experience suggests that the method is not generally known.

The basic principle is that clean tungsten wire can be satisfactorily electroplated with copper, which is subsequently soft soldered. The conditions described below have been used in a typical experiment, but are not represented as critical and could probably be widely modified as desired. The primary requisite is a bright unoxidized tungsten surface, which can be prepared by any of the usual methods—electrolysis in sodium hydroxide solution, dipping into molten caustic soda, rubbing the heated wire with a stick of sodium hydroxide or sodium nitrite. Of these, electrolysis is the neatest and most readily controlled; a few minutes' electrolysis (12 V, ~1 A) in 5% caustic soda solution with the tungsten wire as the anode and a nickel cathode is quite sufficient. The tungsten is then washed and cleaned further by electrolysing for a few minutes in nitric acid (about 1 N), periodically reversing the electrode polarity. After rinsing, copper is electro-deposited from a solution of copper sulphate (about 10 g $CuSO_4$ per 100 ml. solution); a 2 V cell supplies a suitable potential. A low rate of deposition of copper is apparently essential for the formation of a firm even deposit, since too high a current results in a powdery layer, unsuitable as a base for soldering. A satisfactory deposit is obtained by using a current density of 10–20 mA cm^{-2} for 10 min. The firmness of the copper layer can be tried on a test sample by rubbing with the finger. After washing and drying, the copper is tinned with soft solder so that a copper wire, for example, can be easily affixed. Such a joint has effectively no electrical resistance.

The normal procedure can be carried out in 15 min if the materials are ready to hand; several wires can be cleaned and electroplated in a batch if necessary. The method has the advantages of ruggedness and cheapness, since no elaborate apparatus is required.

---

* Now at Department of Physics, The University, Edgbaston, Birmingham, 15.

† Now at Department of Chemistry, The University, Manchester, 13.

A reversible message register

By C. J. Sumner, A.M.S.E., Commonwealth Scientific and Industrial Research Organization, Division of Meteorological Physics, Victoria, Australia

[*Note received* 16 *May*, 1956]

A message register was required capable of both adding and subtracting electrical impulses on a single four-wheel counter. This was done by using the parts of two standard Post Office message registers (type 4055 by Standard Telephones and Cables Ltd.) as follows. The two solenoids are mounted in opposite ends of a metal frame (*A*, Fig. 1). To each armature is riveted a forked arm *B*. The forked arms engage with two operating spindles riveted into a rocking frame *C*. A hole is provided in each side of the frame for a pin *D* which is

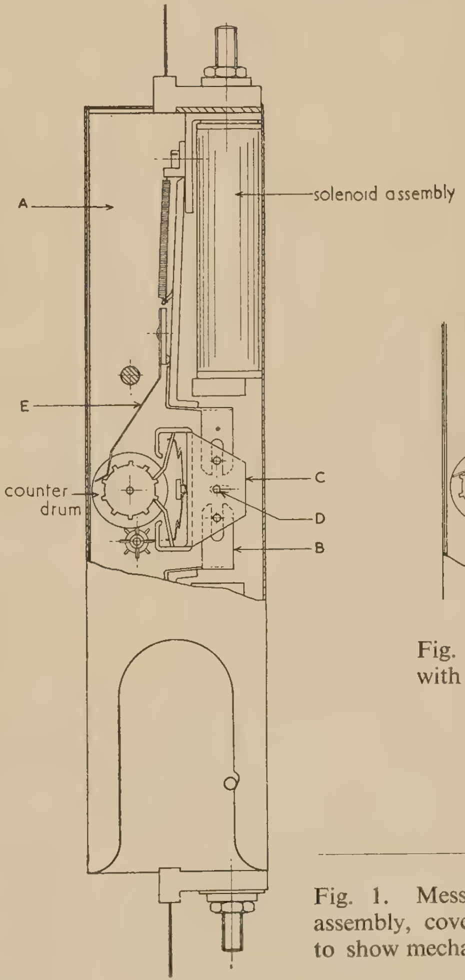


Fig. 1. Message register assembly, cover cut away to show mechanism at rest

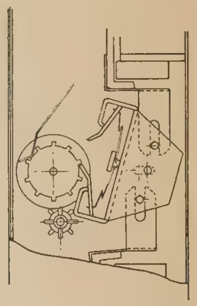


Fig. 2. Mechanism with one solenoid operated

located in slots in the main frame. This arrangement of slots in the forks and main frame allows the rocking frame to rotate about either of the two operating spindles. The rocking frame is constructed to carry the existing message register triggers and springs, one being bent the opposite way to give right and left hand operation. Stops are also included in the rocking frame to locate the triggers in their correct position while disengaged from the sprocket wheel. A detent spring *E* is provided to locate the counter wheels and allow them to be rotated in either direction.

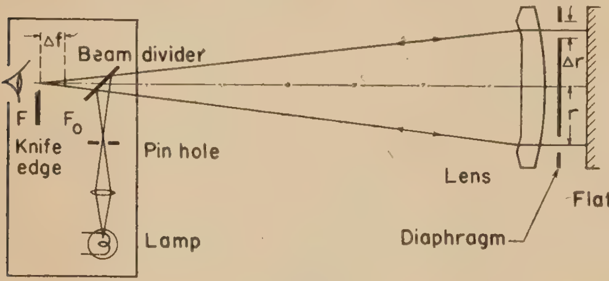
When the two solenoids are at rest the two triggers are located on opposite sides of two adjacent projections on the primary counter wheel sprocket, preventing the counter from being rotated in either direction (Fig. 1). When one solenoid is operated the forked arm drops carrying with it one side of the rocking frame, the stationary forked arm acting as the hinge point. This moves the two triggers so that while one disengages from the sprocket wheel the other advances the wheel one tooth (Fig. 2). When the armature returns to the rest position the two triggers take up their original position on the sprocket. The reverse action is obtained by operating the second solenoid, when a similar movement takes place, but in the opposite direction. The proportions of the mechanism are so arranged that the movement of the solenoid arms imparts a similar movement to the triggers to that obtained with the standard counter.

Quantitative application of the Foucault test to objective lenses

By P. Hariharan, M.Sc., A.Inst.P., National Physical Laboratory of India, New Delhi, India

While the quantitative application of the Foucault test to spherical and paraboloidal mirrors has been discussed extensively,(1, 2) it is not generally realized that the same basic procedure can also be used to measure the surface errors of refracting objectives.

The test set-up is based on the principle of auto-collimation with a silvered flat, as shown in the figure. A set of stops is used to isolate successive annular zones of the lens, say 1 cm wide. The focus of each zone can then be located by finding the point on the axis at which the entire zone appears to darken uniformly as the knife-edge cuts across the beam.



Test set-up

If the outer edge of any given zone of width Δr, located at a mean radius r from the centre of the lens, is raised by an amount Δt with respect to its inner edge, it will produce a deviation $\Delta\phi$ of the rays passing through this zone, given by the relation

$$\Delta\phi = (\mu - 1)\,(\Delta t/\Delta r)$$

As a result, the focal length of this zone is increased by an amount Δf, where

$$\Delta f = f^2 \Delta\phi / r$$

Combining these two equations, we see that

$$\Delta t = [r.\Delta r/(\mu - 1)f^2]\Delta f$$

By summing up the values of Δt obtained for success zones, proceeding from the centre outwards, one can ea obtain the curve showing the departure of the profile of lens from the ideal one for complete spherical correction.

Gaviola's method(2) can also be applied to lenses in same manner. It is particularly suited to the evaluation residual errors after the final figuring operation.

REFERENCES

(1) Young, R. K. *Amateur Telescope Making* (Book p. 376 (New York: Scientific American, 1949).
(2) Gaviola, E. *J. Opt. Soc. Amer.*, **26**, p. 163 (1936).

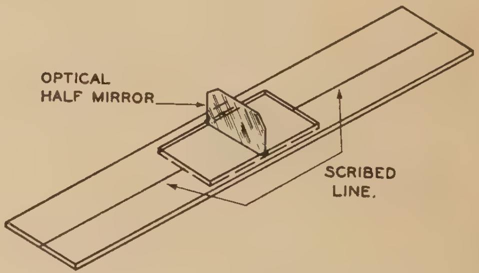
Device for measurement of tangents

By A. R. King, Ph.D.,* Imperial College of Science an Technology, London, S.W.7

[*Note received* 24 *July*, 1956]

In many scientific operations, it is necessary to meas tangents at points on experimentally constructed cur Measurements made by mathematical processes or with a of the instruments available are invariably very laborious inaccurate. The simple instrument described below has be found to give accurate and reproducible results with minim effort.

As shown in the figure, the instrument consists of a Persp base in which is vertically mounted a thin semi-reflect mirror. A straight line is scribed at right angles to the mirr on the underside of the base.



Device for measurement of tangents

Tangents are measured by laying the instrument on th curve with the mirror intersecting it at the desired poin Looking into the mirror, the image of the curve on the ne side is seen side by side with the curve on the far side whic is also visible because of the semi-transmitting quality of th half-mirror. Both are of reduced intensity but, on rotatin the device, the lines may be made to coincide when th intensity will be greatly increased. At this position, th scribed line will be at the tangent slope and intercepts wi give the numerical result.

Where the radius of curvature is small, it is advisable t plot the curve on an extended scale in order to observe mor accurately the coincidence of the lines.

---

* Now at Commonwealth Scientific and Industrial Researc Organization, Fishermen's Bend, Melbourne.

Correspondence

Fringe spacing in interference microscopes

A paper by Mr. Tolmon and Mrs. Wood, published on pp. 236–238 of the June 1956 issue of this *Journal*, shows that he equivalent fringe spacing in high power interference microscopes is greater than half a wavelength, and depends on the numerical aperture of the optical system. The effect is the result of the obliquity of the light incident on the object under examination. If the illumination were restricted to a single angle of incidence (e.g. by an annular stop in the condenser) the fringe spacing could be predicted from the expression given in the paper, $\lambda/(2\cos\theta)$, where θ is the angle of incidence. Usually, however, the illumination in an nterference microscope extends over most of the cone which is accepted by the microscope objective, and in the cases quoted the objective acts as condenser, so that the numerical aperture of the condenser is the same. The whole cone is then filled more or less evenly, depending on the uniformity of the light source and on possible variations in absorption or reflexion losses with angle. If it were not for these uncertainties, it would be possible to predict the equivalent fringe spacing for a microscope of given numerical aperture by averaging the spacings of the slightly different patterns formed by successive annuli of the cone of illumination, making due allowance for the relatively greater flux for the more oblique elements. An attempt has been made to calculate the spacing to be expected and the results are compared below with the spacings found experimentally.

Consider a zone of illumination in a perfect optical system which is bounded by circles subtending angles θ, and $\theta + d\theta$, with the optical axis. The flux in this annulus is proportional to $\theta d\theta$. The fringe spacing may be averaged over the whole aperture by multiplying the fringe spacing $\lambda/(2\cos\theta)$ by $\theta d\theta$ as a weighting factor and integrating over the full cone of illumination α. The result is normalized by dividing by the integral of the weighting factor. The averaged fringe spacing is then

$$\int_0^\alpha (\lambda\theta/2\cos\theta)d\theta \bigg/ \int_0^\alpha \theta d\theta$$
$$= \frac{\lambda}{2}\left(1 + \frac{\alpha^2}{4} + \frac{5\alpha^4}{72} + \frac{61\alpha^6}{2880} + \right.$$
$$\left. + \frac{277\alpha^8}{40320} + \ldots + \frac{E_n\alpha^{2n}}{(n+1)(2n)!} + \ldots\right) \qquad (1)$$

where E_n are Euler's numbers.

In practice the outer zones of the objective are slightly less effective than has been allowed for here. A weighting factor of $\sin\theta d\theta$ instead of $\theta d\theta$ will diminish the effect of the more oblique zones. The averaged fringe spacing is then given by

$$\int_0^\alpha (\lambda\sin\theta/2\cos\theta)d\theta \bigg/ \int_0^\alpha \sin\theta d\theta = (\tfrac{1}{2}\lambda)\ln\cos\alpha/(\cos\alpha - 1) \qquad (2)$$

Values of the coefficients of $\frac{1}{2}\lambda$ in these two expressions to correspond with the experimental results are given below. (*Note*: In the paper the labelling of the seventh line of the table *should read* "Mean percentage correction.")

Numerical aperture	0·30	0·60	0·65
Experimental factor	1·03	1·09	1·12
Calculated from equation (1)	1·02	1·12	1·15
Calculated from equation (2)	1·02	1·12	1·14

The calculated results provide a fair approximation, but it seems likely that the effect of the outer zones is over-estimated in both cases.

Light Division,
National Physical Laboratory,
Teddington,
Middlesex.

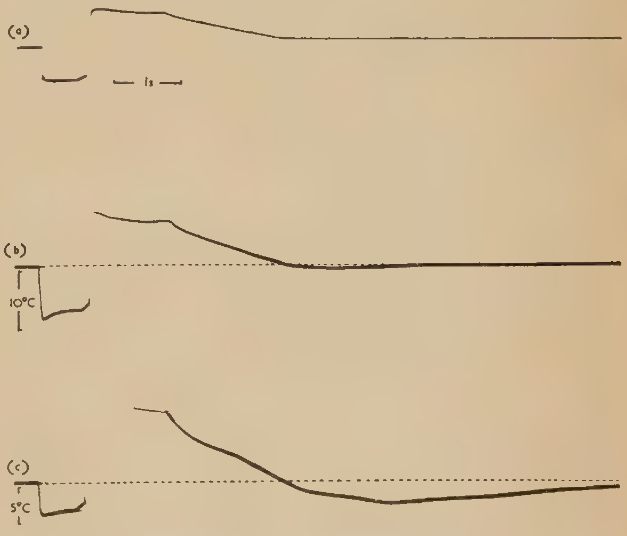
J. W. Gates

Temperature and pressure measurements in an over-compression cloud chamber

Since the publication in this *Journal* of a description of a 9 in. diameter over-compression chamber,(1) measurements have been made of the variation of temperature throughout a working cycle. The results show clearly that the combination of expansion and over-compression can produce the drop in temperature predicted in the earlier paper.

The platinum resistance thermometers employed for these measurements were copies of a type developed by Dr. N. Morris at University College, London, and we are grateful for the detailed advice that he has given. Platinum wire, 5 μ in diameter, formed one arm of a simple Wheatstone bridge network, with a cathode-ray oscillograph to measure the off-balance voltage. The platinum, in the form of Wollaston wire, was wound on a small glass frame, and annealed by passing a current of 1 A for a few seconds, the silver sheath then being dissolved in nitric acid. In a typical case the remaining platinum core, 60 cm long, had a resistance of 3250 Ω at 18° C, which gave a change in resistance of 11·8 Ω per ° C.

The thermometer was supported at the centre of the cloud chamber on an insulating rod attached either to the side walls or to the brass base-plate. Calculations predicted that heat flow along the wire from the glass frame should be negligible,



Pressure and temperature changes during the over-compression cycle

(*a*) Pressure trace.
(*b*) Temperature trace, balanced cycle.
(*c*) Temperature trace, over-compression high relative to expansion.

but to check this effect several thermometers were constructed on various sizes of frame, with resistance varying between 1000 and 3500 Ω. The rapid response of the thermometer and its recording equipment was checked by the application of step-voltages across the wire.

Temperature measurements were made with dry argon only in the chamber to avoid any errors due to condensation of vapour on the platinum wire. The presence of vapour has, however, in the absence of heavy ionization only a small effect upon any temperature changes, as has been shown by Milatz and Van Heerden.(2)

The figure shows the variations of temperature, and also those of pressure as recorded on a capacitance-type gauge. The cooling produced at the end of the slow return of pressure from the over-compressed state is shown clearly in the lower temperature trace (*c*), taken with over-compression high relative to expansion. In contrast the upper temperature trace (*b*) shows a case in which the gain and loss of heat are practically balanced over the cycle. This condition keeps the gas and the chamber walls at the same temperature, except during the actual expansion and compression and thereby minimizes convection currents. Under typical operating conditions, the temperature three seconds after the application of over-compression was 2° C below that at the beginning of the cycle, the depth of this minimum being dependent upon the amount of over-compression applied. When the recycling time was increased from ten to fifteen seconds or longer, the temperature rose by approximately 1° C, thus accounting for the necessary increase in expansion ratio mentioned in the previous paper.

The slow return to equilibrium pressure, the rate of which is not critical, appears to play the role of a cleaning expansion in a conventional chamber. All droplets are not completely evaporated at over-compression, and, in the presence of sufficient vapour, condensation occurs upon the remainin centres during the slow return, enabling droplet depositio to take place more rapidly. The velvet base acts as th source from which alcohol can evaporate rapidly enough cause supersaturation at temperatures above the equilibriu value.

Since for a fixed rate of operation, the expansion rat may be adjusted to take account of any heating or coo ing during an unbalanced cycle, the main limitation to th recycling rate appears to be set by the time needed fo droplet deposition.

Appreciable changes in temperature with the pressu approximately constant at both expansion and over-compression can be clearly seen, typical values being a rise o 1·5° C and a fall of 3·0° C respectively.

These changes are more rapid than those expected for pressure-defined chamber (compare Milatz and Van Heerden and are undesirable because they cause a reduction of sensitiv time. However, they do show the advantage of the over-compression cycle in maintaining thermal balance unde adverse conditions. It is clear that they are coupled wit gas motions produced in the chamber by the expansion an compression mechanism, since removal of the velvet covere base-plate causes an increase both in the gas motions and th temperature changes.

Physics Department,
University of Birmingham.

D. W. HADLEY
J. C. BOWER
J. WALKER

REFERENCES

(1) WALKER, J., TAGLIAFERRI, G., BOWER, J. C., and HADLEY, D. W. *J. Sci. Instrum.*, **33**, p. 113 (1956).
(2) MILATZ, J. M. W., and VAN HEERDEN, C. *Physica*, 1 p. 21 (1947).

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improve products. The Institute of Physics assumes no responsibility for the statements given below: information for these has bee taken from literature supplied.

Precision instrument switches. Croydon Precision Instrument Co. Ltd., 116 Windmill Road, Croydon, Surrey.

These switches are intended for use in precision resistance units, strain gauge and thermocouple circuits. The $\frac{5}{16}$ in. diameter stud contacts are made of hard copper, and the multileaf self-cleaning brush is phosphor bronze. The switch resistance is 1500 $\mu\Omega$ and the contact resistance variation, measured under the worst possible conditions, is 150 $\mu\Omega$. This switch is designed for manual operation only and when it is rotated as rapidly as possible the thermoelectric e.m.f. generated is stated to be less than 1·5 μV. A variety of contact arrangements is available, ranging from a single-pole, 50-way switch to a triple-pole, 6-way switch.

Microprojector. W. Watson and Sons Ltd., 313 High Holborn, London, W.C.1.

The Watson microprojector has been designed for the efficient projection of microscope preparations by transmitted light at screen magnifications of up to approximately 5000 diameters. It is claimed that excellent image brilliancy is maintained for a picture diameter of 8 ft at projection distances as great as 40 ft.

Selection of the objective magnification is made by a single control. Except for a control unit supplying the light source and which may be at any convenient distance from the microprojector, the instrument is entirely self-contained and enclosed. Lens surfaces are coated to increase light transmission and to improve image contrast. The mechanism for adjusting the focus and changing of objectives and condensers are enclosed within a limb, on which is assemble the entire microscope unit with mechanical stage. The contro heads for both coarse and fine focusing adjustments are coaxial.

The mechanical stage has a flat top plate 6 in. (15·5 cm square with lateral mechanical motion of 100 mm and a transverse movement of 50 mm. Vernier scales allow particular areas of an object to be located to an accuracy o 0·1 mm. Slides of any size from 3 × 1 in. to 4 × 2 in. car be accommodated.

The eyepiece turret enables an instantaneous change between two eyepieces to be made without disturbing the focus. Each eyepiece is fitted with a prism which directs the emergent beam at the desired angle; the prism is integra with the eyepiece.

Three eyepieces are available, ×2·5, ×3·5, ×4·5 and the three objectives supplied, normally with initial magnifying powers ×4, ×10, ×40, are mounted on a cylindrical changer hich rotates to bring each objective into the optical axis turn. For each objective there is a matched condenser in similar cylindrical changer mounted beneath the stage. oth changers are geared to a single control lever so as to ve a positive location with common focus and centration r all three combinations. A shroud surrounds each bjective to avoid glare caused by light scatter within the icroscope slide.

The light source is a high pressure discharge lamp which is ntended to operate through the control unit from a.c. mains upply of 190–260 V, 50 c/s with a power consumption of 50 W. A d.c. mains supply of similar voltage range may lso be employed, but only with a special control unit which ncreases the power consumption to approximately 1 kW. he lamp reaches full intensity approximately 10 min after eing switched on. It is claimed that after this initial period he arc is quite stable and at all times quite silent in operation.

hotoelectric colorimeter. W. Harrison, Station Road, Midge Hall, Preston, Lancashire.

his photoelectric colorimeter has the following features. A 2 V lamp, in conjunction with a lens, provides a beam of ght which is incident on the sample at an angle of 45°. A wo-component blue glass daylight filter is attached to the ens mount to give the equivalent of illuminant C. When the aylight filter is replaced by a neutral filter, illuminant A is btained. Four colour filters in conjunction with a selected arrier-layer photocell measure the light reflected normally rom the sample. The filters give a very close approximation o the C.I.E. standard observer. The current from the photoell is measured on a sensitive galvanometer. A standard ell and a resistance network with six-way switch provides a eutralizing current opposing the photoelectric current and ives an effect equivalent to a six-fold lengthening of the alvanometer scale.

The effect of any fluorescent material in the sample can be xamined by the means of a "black" glass ultra-violet filter. Measurements can readily be converted to the C.I.E. colour cale.

Vacuum switch controller. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

The model VS.4 vacuum switch controller gives positive and utomatic electrical switching in the pressure range 2·0 to 0·02 mm of mercury and will either open or close circuits t a given pressure. It consists of a VS.4 head and a control nit connected by a 6 ft (1830 mm) length of insulated cable. The head is mounted in the vacuum system by brazing or oldering on to the liner of the ½ in. vacuum union ncorporated.

The head contains an operating contact held shut by a wire with a high coefficient of thermal expansion. The wire is heated electrically and as the pressure falls the loss of heat by conduction through the gas is reduced and its temperature rises, resulting in an expansion of the wire and consequent opening of the operating contact. The pressure at which the contact opens is determined by the power applied to the wire. To prevent overload, a second contact closes should there be excessive filament expansion.

In order to suppress arcing and the build up of decomposition products formed in the discharge the current and voltage across the gauge head contacts are held to very small values, less than 2 μA or about 10 V "open contact" voltage. This small current actuates the grid circuit of a thyratron (gas filled) relay valve having magnetic relays in its anode circuit. Heavy duty contacts on the magnetic relay are available for the switching of external apparatus.

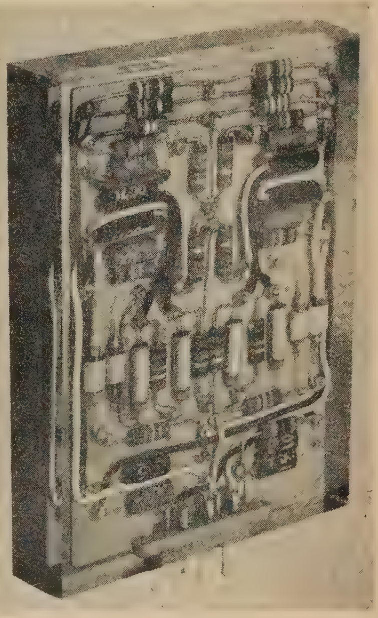
The controller provides the necessary stabilized power supply for the head, houses the switching and relay circuits, and includes a device for protecting the thyratron valve when first switching on.

A range switch on the controller can be set to an upper or a lower pressure range and range controls allow the appropriate switching point to be selected on a linear scale. If the pressure in the vacuum system varies below or above that indicated by the selected range control, a magnetic relay will operate the appropriate indicator lamp. Provision is made for reversing this sequence to obtain the "failed safe" condition.

The range switch can also be set to an "automatic" position, in which case the two ranges are in effect combined. An upper and a lower pressure can be selected by the appropriate controls and each time the magnetic relay operates the range will change. This makes possible cycling operations between the two set pressures.

Transistor decade counter and scaler. Venner Electronics Ltd., Kingston By-Pass, New Malden, Surrey.

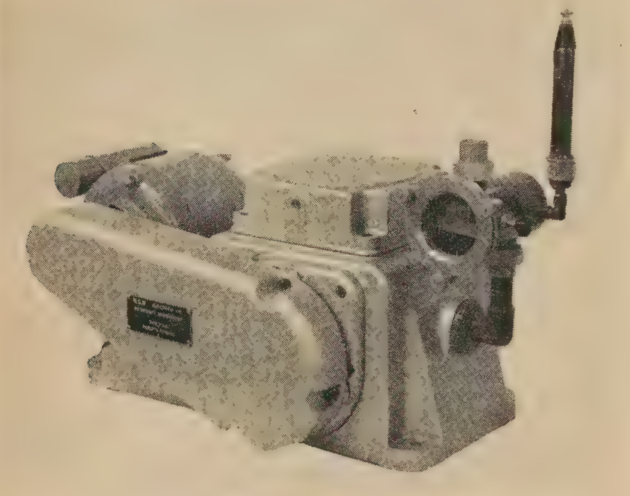
The unit illustrated in the figure employs transistors and germanium diodes arranged in four Eccles–Jordan stages with feedback. It forms a stable decade counter operating at frequencies from zero up to 30 kc/s. It is considerably smaller than equivalent cold cathode counting tubes and their associated circuitry and has a total consumption of 100 mW as a scaler or 160 mW as a counter. Only one power supply of 10 V is required. Heating of the unit is negligible, and therefore it should have a very long life. The construction is interesting inasmuch as some eighty-six components, including eight transistors and eight diodes, are assembled on a double-sided tagboard of size 4 × 3 in. This is then encapsulated in epoxy resin to form a block of size $4\frac{1}{2} \times 3\frac{1}{4} \times \frac{3}{4}$ in., which is fitted with an eight-pin plug so that the unit is ready for direct insertion into equipment. One decade may be connected directly to another with no additional components and thus, by using four in cascade



Transistor decade unit. The unit shown has been encapsulated in clear resin to show the internal construction. Production units are encapsulated in filled resin and are therefore not transparent fed from a transistorized 10 kc/s crystal oscillator (made by the same firm), an output pulse every second may be obtained. Alternatively, by connecting a meter to each stage and feeding the decades from the crystal oscillator with a switch to interrupt the flow of pulses from the oscillator, a short period timer is obtained which indicates on the meters (to the nearest 0·1 ms) the time for which the switch has been closed.

Vacuum pump. N.G.N. Electrical Ltd., Cawdor Street, Patricroft, Manchester.

A range of high vacuum rotary piston pumps are being made to a new design. The makers claim that with their new method of pumping combined with the patented exhaust valve these pumps work very quietly and have an ultimate vacuum better than 0·005 mm of mercury with the single-stage pump and better than 0·0005 mm with the two-stage pump.


Rotary piston pump

All pumps are supplied with an adjustable gas ballast valve as a standard fitment, to enable the pumps to deal with a reasonable proportion of condensible vapours. The pump bodies are constructed from high grade cast iron and the cases are of light alloy. The pulleys are fitted with quick release Fenner taper lock bushes and the pump is removable from the case for maintenance purposes. The range available is in five sizes from 1 to 12 ft^3/min, and may be supplied with motors to suit most voltages.

Plastic dust covers. E. S. and A. Robinson Ltd., Redcliffe Street, Bristol, 1.

Transparent, "tailor-made," plastics dust covers for scientific instruments are now being produced. The permanently flexible covers, which will not rot or perish, are claimed to be more hygienic than woven fabrics and they can be easily washed in tepid soapy water.

These covers are a natural development of the "contour" bags produced by the company as novelty packs and for enclosing awkward shaped articles, such as toys, cushions, etc. The development of a special heat-sealing technique and the installation of new plant enables contour bags—which are made under British patents—to be produced from any sheet plastics, in any thickness, overprinted with multi-colour illustrations if desired. The seams of the covers are heat-sealed, so forming a strong airtight weld and obviat any fear of tearing which is prevalent with stitched covers.

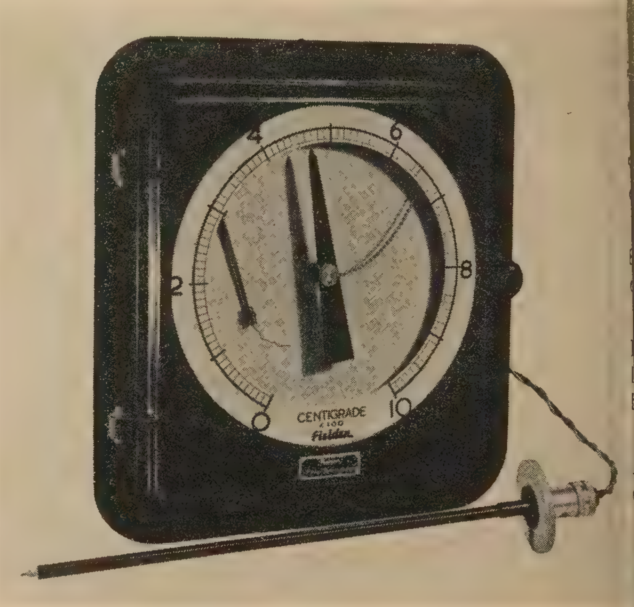
Geiger tubes. Radiac Co., 489 Fifth Avenue, New York U.S.A.

Geiger tubes which are γ-ray detectors are intended partic larly for use in uranium prospecting equipment. They cons of a bundle of Geiger tube elements in a common housi the cathodes being in the form of grid-like screens. This claimed to increase the chances of producing ionization, that a greater proportion of the incident radiation results an electron avalanche. It is also claimed that the "multiplier" tubes are ten to fifty times more sensitive th conventional Geiger tubes. The sensitivity is given as: of t order of 5×10^5 counts per minute per milliröntgen per hou

Recording thermocouple pyrometer. Fielden Electronics Lt 21 Buckingham Street, London, W.C.2.

The Pyro-Servograph is a temperature recorder which operat in conjunction with thermocouples and it can be suppli for use with either base metal or precious metal therm couples in various ranges, from 0 to 300° C upwards. Aut matic cold junction compensation is provided and the make claim an accuracy of ±1% for the equipment.

The output from a thermocouple is fed to a moving-c millivoltmeter fitted with sprung jewel pivots. This movin coil movement has the normal indicating pointer replace by a light metal vane which acts as one plate of a varia condenser. Another similar vane, turned by a serv mechanism moves in the same arc as the meter operate vane, the two vanes being maintained at a constant spacin by an electronic capacity relay which controls the servo motor. A pen arm is coupled to the servo-motor an follows the change of position of the meter vane. The moto has a reserve of power for operating alarm or contro mechanisms and for driving a large control indicating pointer.



Recording thermocouple pyrometer

The two valves employed are standard types, the electroni chassis is a plug-in unit and the motor and other movin parts are readily accessible and interchangeable.

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

Fuel hose. Thomas Boorn and Co. Ltd., Venn Street, apham, London, S.W.4. An illustrated 30-page brochure scribes "Flylite" aircraft fuel hose and ancillary equipment ends, anchorage, couplings, etc.).

Tube manufacturing practice and specifications. Accles and ollock Ltd., Oldbury, Birmingham. A 96-page book gives mprehensive information and technical details of the m's wide range of products together with some notes on anufacturing practice.

Electron microscopes. North American Phillips Co. Inc., struments Division, 750 S. Fulton Avenue, Mt. Vernon, .Y. A 4-page folder gives particulars of the Norelco electron icroscopes types EM-100B and EM-75 and lists instrument atures and typical applications.

Miniature precision potentiometers. Computer Instruments orporation, 92 Madison Avenue, Hempstead, L.I., N.Y. series of leaflets describes a range of miniature and subiniature potentiometers incorporating non-inductive carbon m resistance elements and potentiometer elements.

Miniature precision commutator. Computer Instrument orporation, 92 Madison Avenue, Hempstead, L.I., N.Y. leaflet describes miniature precision commutators for use high-speed switching devices.

Resistance thermometer. Savage and Parsons Ltd., Watrd, Hertfordshire. Leaflet 3/5 describes the SP platinum sistance thermometer which has a remote reading instruent made in four ranges between −50 and 150° C, and ading to ±0·1° C.

Iris diaphragms. J. H. Dallmeyer Ltd., Church End Works, illesden, London, N.W.10. Leaflet D/2180 gives full details a range of iris diaphragms.

Enlarging lenses. J. H. Dallmeyer Ltd., Church End orks, Willesden, London, N.W.10. A leaflet gives details a range of four element, anastigmatic, enlarging lenses.

Square pulse generator. Nagard Ltd., 18 Avenue Road, elmont, Surrey. Details of a wide-range, delayed square ulse generator, type 5001, are given in Sheet 5561.

Standard parts for jigs and fixtures. J. B. Purefoy Unit ooling Ltd., Upper Tilt Works, Cobham, Surrey. An ustrated catalogue entitled *Purefoy unit tooling* provides full etails of a range of standard parts for jigs and fixtures.

Jointing compounds. The Kenilworth Manufacturing Co. td., West Drayton, Middlesex. A leaflet describes a range jointing compounds.

Electric surface heaters. Isopad Ltd., 30–32 Rosemont oad, London, N.W.3. Leaflets describe and illustrate arious types and applications of electric surface heaters.

Servo and remote control elements. Muirhead and Co. td., Beckenham, Kent. Data sheets give full details of a nge of servo and remote control elements (synchros) anufactured to American Bureau of Ordinance specificaons. Brief descriptions are also available of equipment milar to that used for testing synchros.

Electrical engineering data sheets. Johnson, Matthey and o. Ltd., 73–83 Hatton Garden, London, E.C.1. Further ata sheets have been issued on standard tubular contacts, ontact bi-metal and two coat silvering of glass and ceramics.

Metals and alloys. Johnson, Matthey and Co., Ltd., Hatton Garden, London, E.C.1. A copiously illustrated booklet entitled *An industry within industry* surveys the activities of this firm.

X-ray apparatus. C. H. F. Müller, 7 Mönckebergstrasse, Hamburg 1. A range of English language catalogues gives full details of the X-ray equipment produced by this firm.

Electrical testing equipment. The Hickok Electrical Instrument Co., 10514 Dupont Avenue, Cleveland 8, Ohio. Catalogue number 31 describes a range of electrical testing equipment.

High vacuum, rotary piston pumps. N.G.N. Electrical Ltd., Cawdor Street, Patricroft, Manchester. Leaflet 881/16 provides full details of a range of high vacuum, rotary piston pumps.

Laboratory apparatus. Charles Hearson and Co. Ltd., 68 Willow Walk, Bermondsey, London, S.E.1. Leaflets describe a wide range of laboratory apparatus.

Vacuum impregnation control equipment. Addison Electric Co. Ltd., 10–12 Bosworth Road, London, W.10. A leaflet describes a range of vacuum impregnation recorders.

Nuclear instruments. Detectolab, Inc., 6544 North Sheridan Road, Chicago 26, Illinois, U.S.A. A twenty-three page catalogue describes a range of nuclear instruments which includes pulse height analysing instruments, scalers, control panels, counting rate meters, regulated high-voltage supplies, scintillation detectors and flow counters.

Potentiometers. W. G. Pye and Co., Ltd., Granta Works, Newmarket Road, Cambridge. Leaflet 7568 describes a precision vernier potentiometer, leaflet 7565, a universal precision potentiometer and leaflet 7569/P a portable potentiometer with a built-in galvanometer, battery and standard cell. All can be delivered from stock.

Capacitors. The Plessey Co., Ltd., Components Division, Kembrey Street, Swindon, Wilts., Notices announce a complete range of sub-miniature electrolytic capacitors and wax-protected tubular paper capacitors.

Multi-purpose spot-follower recorder. Sefrom, 74 Rue de la Fédération, Paris 15. A leaflet describes the Photodyne which is a photoelectric device for following the movements of a spot of light and registering it by pen on a moving paper chart.

Gamma-radiation survey equipment. Edison Swan Electric Co., Ltd., 155 Charing Cross Road, London, W.C.2. A 2-page press release describes a mobile uranium prospecting outfit.

Chemical laboratory apparatus. Griffin and George Ltd., Ealing Road, Alperton, Wembley, Middlesex. Calalogue 56S is a beautifully produced 700-page illustrated list of products for use in chemical laboratories, including modern apparatus employing physical methods of analysis. Among the newly designed pieces of apparatus described in the catalogue are: electrochemical analysis apparatus; vapour phase chromatographic apparatus; bomb calorimeter; skeletal atomic models; B.D.H. deionizer; analytical balances. The volume opens with some useful notes on laboratory planning. It is arranged in convenient sections for ready reference and has an excellent index.

Notes and comments

Competition of craftsmanship and draughtsmanship

The Physical Society will again hold its annual craftsmanship and draughtsmanship competition for apprentices and learners in 1957. Competitors must be under 22 years of age on 31 March, 1957. The classes under which work may be submitted are again (i) scientific instruments and components; (ii) tools and gauges; (iii) optical components and systems; (iv) blown-glass and silica ware; (v) sections of instruments, functional scale models of scientific interest and patterns; (vi) draughtsmanship.

The entries submitted will be displayed at The Physical Society's annual exhibition of scientific instruments and apparatus which will be held from 25 to 28 March, 1957, and a selection of the prizewinning entries may be transferred to The Science Museum for a short period following the exhibition. Further details may be obtained from The Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7, and entry forms must be returned by 21 January next.

Physics in Medicine and Biology

We have received the first issue of a new periodical entitled *Physics in Medicine and Biology*, which is the Journal of the Hospital Physicists' Association and is published in association with the *Philosophical Magazine* under the editorship of Professor J. E. Roberts. The primary object of the new Journal is to report results of original researches by physicists and others in the two main fields; (*a*) studies of the physical properties and constitution of living matter at all levels of organization, and (*b*) applications of physics and the methods of physics to the elucidation of problems in medicine, biology and physiology. This first issue runs to 102 pages measuring $6\frac{3}{4} \times 10$ in. and contains the following papers: Recent advances in electrophoretic separation methods for biologically important substances, by C. J. O. R. Morris; The present status of calibrations of ionization dosemeters with high-voltage X-rays, by G. P. Barnard, E. J. Axton, D. S. C. Belcher and A. R. S. Marsh; Microspectrophotometry with the Burch reflecting microscope, by K. W. Keohane and W. K. Metcalf; A profile counter and its calibration, by B. D. Corbett, R. M. Cunningham, K. E. Halnan and E. E. Pochin; Analysis of the radioactive content of tissues by α-track autoradiography, by J. Rotblat and Gillian Ward; Instrumental notes—Some recent nucleonic instruments for use in clinical work, by E. W. Pulsford. In addition to the papers there is a book review and 245 brief abstracts of papers published in other journals; the abstracts are to be a regular feature of the new journal. There are to be four parts to a volume of approximately 400 pages, price £1 ($3.00) per part, and the annual subscription price is £3 10*s*. per volume post free ($10.50 in U.S.A. and Canada). The new journal is printed and published by Taylor and Francis Ltd., of Red Lion Court, Fleet Street, London, E.C.4.

Fourth general assembly and international congress of International Union of Crystallography

The International Union of Crystallography has accep the invitation of the National Research Council of Cana to hold its Fourth General Assembly and Internatio Congress in Canada from the 10th July to the 17th Ju 1957, followed by two Symposia on the 18th and 19th. the Congress papers will be presented on all aspects of cr tallographic research; the subjects of the Symposia will "Physical techniques of crystallographic interest" a "Electron diffraction." Through the co-operation of McC University and the University of Montreal, the meetings being held in the City of Montreal. Technical excursions other parts of the Province of Quebec and to sections of Province of Ontario are being arranged.

The Canadian National Committee on Crystallography acting as the local committee of the Congress and has pr pared a brochure giving details of the technical programm topics, and accommodation for the Congress. Copies this have been forwarded to the Secretaries of the natio committees of the member countries of the Union. Cop may be obtained from them; from the General Secretary the Union, Dr. D. W. Smits, Laboratorium voor Anorganisc en Fysische Chemie, Bloemsingel 10, Groningen, The Neth lands; or from the Secretary of the Canadian Committ Dr. W. H. Barnes, Division of Physics, National Resear Council, Ottawa 2, Ontario, Canada (envelope to be clea marked "Personal"); or from the Chairman of the Program Committee, Dr. W. N. Lipscomb, School of Chemist University of Minnesota, Minneapolis, U.S.A.

Erratum

In the note "Adhesives for galvanometer mirrors" Norah W. Sullivan published on p. 362 of the Septemb 1956 issue of this *Journal*, the adhesive silicone F. 40 which is mentioned twice, *should read* silicone F. 3044.

British Journal of Applied Physics

Contents of the December issue

CONFERENCE REPORT

Summarized proceedings of a conference on low temperature crystallograph Oxford, April 1956. By D. W. J. Cruickshank, E. Mendoza and J. Robertson.

ORIGINAL CONTRIBUTIONS

A photoelastic method employing scattered light for the solution of plane str problems. By W. Shelson and I. W. Smith.

Flying spot counting and sizing of non-uniform particles. By H. W. Loeb.

The elastic properties of dilute aqueous gels. By L. J. Hastewell and R. Rosc

Viscosity and action. By T. V. Starkey.

Vibrations of an end-loaded strip. By H. S. C. Chen.

NOTES AND NEWS

Correspondence

The application of the centripetal effect in air to the design of a pump. Fr B. Popper and M. Reiner.

Corner fractures in explosively loaded thin-walled steel cylinders. From S. Sin

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £5 per volume ($14.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 10*s*. each ($1.50 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

INDEX TO VOLUME 33

SUBJECTS

Abrasion tester, Thin film 240
Absorptiometer, An X-ray, for the determination of tetraethyl lead in petrol 222
Absorptivities for solar radiation, An instrument for measuring 356
A.C.-D.C. converter 454
A.C. power system studies, Terms used in 248
Adhesives for galvanometer mirrors 362 (*erratum*) 512
Aerosols, radioactive, Application of the electrostatic precipitator to the measurement of 142
Air
  lines in glass tubing, An illuminator for detecting 239
  lock for ionization gauges, A simple 83
  of controlled relative humidity for hygrometer calibration and testing, An apparatus for producing 273
Alinement and co-ordinate system for nuclear emulsion stacks, An 381
Amplifier
  A heart pulse, and ratemeter 440
  An input, for a pulse-height analyser 187
  transistor, Multi-range test meter using 38
Amplitude stabilizer, A microwave 363
Analogue, An electronic, of the saturated vapour pressure curve of water 436
Analyser, magnetic, for high energy particles, A 151
Analyser of uranium content in process streams, An automatic 467
Analysis of very small gas samples, A method for rapid 254
Anemometer, Dines, The use of a ball-point recording system on the 280
Anemometer, Linear, constant-temperature, hot-film 287
Angle-spring hinges 245
Angular displacements, small, The use of polarized light for the measurement of 20
Antimony bolometer, A semiconducting 338
Arc and spark stands and source units 39
Arc chamber, for radioactive materials, A d.c. 359
A.S.T.M. index of X-ray powder diffraction patterns, Errors in the 86
Atomic energy research at Harwell, erratum 128
Attenuator, A secondary microwave 448
Audio-frequencies, A precision electrodeless conductance cell for use at 313

Ball-point recording system on the Dines anemometer, The use of a 280
Barium titanate transducers 287
Barometers, millimetre mercury, Correction of 126
Bar specimens, metal, Measurement of the damping of, in mechanical resonance 123
Baths, A water-driven device for filling, aerating and agitating 320
Beam brightening device for transient recordings, An automatic cathode-ray oscilloscope 203
Beam splitter with illumination control, A 202
Beckman quartz spectrophotometer, A constant temperature solubility cell or reaction vessel for a 27
Beta-gamma radiation monitor, A portable 83
Betatron toroid, On internally metallizing a, by vacuum deposition 445
Bibliography of information on servo-mechanisms and related subjects 168
Bibliography of mechanisms, An international 168
Bimetallic contacts, Corrosion at 288
Binary-coded information, The use of octal numbers for recording 405
Biological tissue, An apparatus for the production of controlled lesions in, without stimulation 450
Birmingham proton synchrotron
  An analysis of injection phenomena in the 102
  The principles and apparatus for the injections system of the 52
Bolometer, A semi-conducting antimony 338
Bolometers, A simple theory for solid-backed 115
Books, New
    Aberrations of thin lenses 452
    Actes du 2^e^ congres international de photographie et cinematographie ultrarapides (Paris, September 1954) 452
    General aspects of radio interference. British Standard Code of Practice CP 1006: 1955 205
    Handbook of meteorological instruments. Part 1 453
    Instrument engineering, Vol. 3, *Part* 1 453
    Instruments for measurement and control 285
    Kleines Handbuch Technischer Regelvorgänge 453
    Knife-edge bearings 205
    Neolaborograph, The: theory and practice 205
    Theodolite design and construction 285
    Time measurement 285
    Vacuum valves in pulse technique 205
    X-rays; their origin, dosage and practical application 452
Boundary-layer exploration, A remotely-controlled traversing yawmeter for 173
Bridge
  circuit for the accurate measurement of pulse impedance, A simple 364
  earthing device, A modified 184
  portable temperature-chlorinity, for estuarine investigations and sea water analysis, A 329
British Chemical Engineering 288
British
  electrical products, Catalogue of 40
  manufacturers, Register of 88
  scientific instruments, Directory and handbook of 168
  scientific instruments, Permanent display of 128
  Standards Institution 408
"Bunsen," Electric 247

Cable cleats 366
Calibration
  and performance, The language of instrument 249
  of a stroboscopic light 204
  temperature, of a high-temperature X-ray diffraction camera, The 41
Calorimeter
  for measuring energy absorption from pile radiation, A 46
  isothermal micro-, An 58
  microwave thermistor, A 353
Calorimetric method of determining the energy output of radioactive materials, A 230
Calorimetry by the method of mixtures 211
Cambridge Instrument Co. Ltd. 408
Camera
  of large capacity, A new vacuum plate- 465
  stand, A simple universal X-ray 82
  X-ray diffraction, The temperature calibration of a high-temperature 41
Cameras
  diffraction, Miniature, for micro-focus X-ray units 161
  high temperature X-ray, A window material for 445
  single-crystal and powder X-ray, A flexible mount for specimens in 318
  User specification for high-temperature X-ray powder diffraction 288
Capacitance-resistance hygrometer, A 36
Capacitor, Decade 246

- Capacitors, Ceramic 327
- Catalogue of British electrical products 40
- Catalogue of nuclear reactors 167
- Cathode lamps, Hollow 127
- Cathode-ray
  - oscilloscope beam brightening device for transient recordings, An automatic 203
  - oscilloscope for twenty-four traces 166
  - tube, Four-gun 38
  - tube with electrostatic focus 247
- Cavities in dielectrics, A servo-mechanism for the study of self-extinction of gaseous discharges in 7
- Cell, constant temperature solubility, or reaction vessel for a Beckman quartz spectrophotometer, A 27
- Cell for kinetic measurements of gas evolution from systems irradiated by fast electron beams 64
- Cellophane sealing iron 39
- Ceramic capacitors 327
- Chart analyser, A semi-automatic pen-recorder 228
- Chimney, Measurement of the optical density of smoke in a 495
- Chlorinity bridge for estuarine investigations and sea water analysis, A portable temperature- 329
- Circuit
  - , A fast multiple coincidence 72 (*errata*) 208
  - , A simple monitor, for a spectrographic a.c. arc source 226
  - , A wide range, recording, logarithmic photometer 69
  - for use in optical pulse-counting systems, A simple direction-sensitive phototransistor 483
  - , Improved ionization gauge control, An 488
- Cleats, Cable 366
- Closures and electrodes, Simple high-pressure 160
- Cloud chamber
  - , A high-pressure diffusion, in a pulsed magnetic field 302
  - , A simple fast-recycling 113
  - illumination unit, A 324
  - , over-compression, Temperature and pressure measurements in an 507
- Coincidence system, A fast, for the measurement of short lifetimes 429
- Cold traps, A liquid level regulator for replenishing 322
- Colorimeter, photoelectric 509
- Condensers, diffusion pumps and, A simple water failure guard for 199
- Conductance cell for use at audio-frequencies, A precision electrodeless 313
- Conducting glass, Laboratory furnace with rotating table for producing 320
- Conduction-cooled vapour traps 245
- Conference on
  - engineering fastenings, Report of a 168
  - magnetism and magnetic materials 167
  - the physics of nuclear reactors 248
- Congress of the International Union of Crystallography, Fourth general assembly and international 512
- Connectors, Electrical 127
- Contacts, bimetallic, Corrosion at 288
- Contacts, vibrating, The measurement of frictional forces at 213
- Controller, Temperature cycle 494
- Controller, Temperature, for an electric furnace 365
- Control, Some principles of measurement and 457
- Converter, A.C.-D.C. 454
- Converter, A mechanical binary-decimal 18
- Copper foil, Electro-deposited 246
- Copper, laminated, A method of preparing 33
- Correction of millimetre mercury barometers 126
- Corrosion at bimetallic contacts 288
- Corrosive liquids, A control valve for 244
- Cosmic-ray recorder, A "hodoscoped" 308
- Coulometric titrations using a pulse technique 323
- Counter
  - and scaler, Transistor decade 509
  - , Geiger-Müller, An oxygen-quenched 185
  - , indium foil, for the measurement of neutron flux, An 404
- Counter—*continued*
  - , scintillation, for the assay of radioactive gases, A 1
  - tube for X-ray diffraction analysis, A proportional 209
- Counters, X-ray proportional, Some notes on the design a performance of 96
- Counting systems, optical pulse-, A simple direction-sensitiv phototransistor circuit for use in 483
- Covers, dust, Plastic 510
- Craftsmanship and draughtsmanship, Competition of 40, 512
- Creep and fatigue testing, An automatic electromechanical stressin unit for 409
- Cryostat, An improved helium liquefier and 148
- Crystallography, Fourth general assembly and internationa congress of the International Union of 512
- Crystal(s), single, *see* Single crystal(s)
- Curvature, Precision measurement of small radii of 487
- Cut-off, A high vacuum magnetic mercury 243
- Cut-off, A mercury, for transferring gas at atmospheric pressur into a high vacuum 318
- Cycle controller, Temperature 494
- Cylinders, The generation of accurate 501

- Damping of metal bar specimens in mechanical resonance, Measurement of the 123
- Dark current of photomultipliers, On the reduction of the 476
- Data, Nuclear reactor 88
- Data, psychrometric, The direct evaluation of, from dry- and wet-bulb recorders 199
- D.C., A.C.-, converter 454
- D.C. arc chamber for radioactive materials, A 359
- Decade capacitor 246
- Deflexions, Some parasitic, in parallel spring movements 11
- Delay lines, High-fidelity 326
- Demagnetization of magnets due to contact with ferromagne bodies 311
- Density, optical, of smoke in a chimney, Measurement of the 49
- Deposition, vacuum, On internally metallizing a betatron toroid b 445
- Desorption system, A simple, for obtaining temperatures abov that of liquid helium 31
- Detector, An electrostatic null 411
- Development, Fine grain, in xerography 194
- Dielectric test cell for liquids, A simple, small 315
- Dielectrics, A servo-mechanism for the study of self-extinction o gaseous discharges in cavities in 7
- Diffraction patterns, optical, Apparatus for the electronic presentation of 24
- Diffraction, X-ray, *see* X-ray diffraction
- Diffractometer, A monitored Geiger-counter X-ray powder, wit automatic recording 204
- Diffractometer, X-ray, A versatile, for single-crystal and powder studies 138
- Diode, Germanium junction 326
- Direction-sensitive phototransistor circuit for use in optical pulse-counting systems, A simple 483
- Directory and handbook of British scientific instruments 168
- Discharges, gaseous, in cavities in dielectrics, A servo-mechanism for the study of self-extinction of 7
- Dispersion meter 454
- Displacements, small angular, The use of polarized light for the measurement of 20
- Documentation of molecular spectroscopy (D.M.S. system) 88
- Draughtsmanship, Competition of craftsmanship and 40, 512
- Dry- and wet-bulb recorders, The direct evaluation of psychrometric data from 199
- Dry cells, Miniature 207
- Dust covers, Plastic 510
- Dust sampling, A portable instrument for respirable 395
- Dynamometer for tensile testing of high polymers 432
- Dynode voltage control, Modifications of photomultiplier characteristics by 163

Earthing device, A modified bridge 184
E.H.T. power unit 39
Electric "Bunsen" 247
Electric strength of insulating liquids, Rotating electrode unit for measurements of the 163
Electrical
  connectors 127
  connexions, A simple demountable vacuum seal for 402
  products, British, Catalogue of 40
  recorder, Two-axis 454
Electrode for molten salt systems, An all-glass reference 438
Electrode unit, Rotating, for measurements of the electric strength of insulating liquids 163
Electro-deposited copper foil 246
Electrodes, Simple high-pressure closures and 160
Electrodes, spherical metal, Preparation and maintenance of, in hydrogen 400
Electromagnet 247
Electromagnet, A general purpose 234
Electron
  beams, fast, A cell for kinetic measurements of gas evolution from systems irradiated by 64
  microscope, EM-3, Calibration of the specimen tilt device of the 307
  multipliers, Transit time spread in 36
Electronic
  analogue of the saturated vapour pressure curve of water, An 436
  presentation of optical diffraction patterns, Apparatus for the 24
  temperature controller 206
  thermometer 326
Electronics for spectroscopists 128
Electrostatic focus, Cathode-ray tube with 247
Electrostatic null detector, An 411
Electrothermal potentiometer 407
Emulsion layers, nuclear, An automatic device for fixing thick 296
Emulsions, nuclear, An automatic scanner for 135
Energy absorption from pile radiation, A calorimeter for measuring 46
Energy output of radioactive materials, A calorimetric method of determining the 230
Equatorial use, A water vapour recorder for 132
Errors in the A.S.T.M. Index of X-ray powder diffraction patterns 86
Estuaries, An instrument for the measurement of salinity in 424
Estuarine investigations and sea water analysis, A portable temperature-chlorinity bridge for 329
Evaporator, A simple rotary film 446
Exhibition
  of instrumentation 456
  of supervoltage machines for X-ray therapy 40
  , The Physical Society's—London, 1956 289
  , The Physical Society's, of scientific instruments and apparatus 128
Extractor, Conical ground joint 400

Fastenings, engineering, Report of a conference on 168
Fatigue testing, An automatic electromechanical stressing unit for creep and 409
Ferromagnetic bodies, Demagnetization of magnets due to contact with 311
Field ratemeter 246
Film
  evaporator, A simple rotary 446
  thickness, The measurement of, with a pneumatic hypodermic needle mechanism 333
  , Thin, abrasion tester 240
Filters, Narrow-band, for use in the ultra-violet spectral region 286
Fine measurements 369
Flow counter, helium, An easily constructed 322
Flow, Regulator for maintaining a constant gas, through a restriction of variable resistance 449
Fluorescence analysis, X-ray, Attachment for 37
Fluorescent powders, Photometer for assessing relative luminances of 27
Flux, neutron, An indium foil counter for the measurement of 404
Foil, copper, Electro-deposited 246
Foucault test, Quantitative application of the, to objective lenses 506
Fragile specimens for examination, A method of storing mechanically 451
Frequencies, very low, Oscillator for 286
Frictional forces at vibrating contacts, The measurement of 213
Fringe spacing in interference microscopes 236, 507
Furnace
  electric, Temperature controller for an 365
  , laboratory scale chill-casting vacuum induction, A 22
  , Laboratory, with rotating table for producing conducting glass 320
  over-temperature protection device, A 201

Galvanometer mirrors, Adhesives for 362 (*erratum*) 512
Galvanometers for instrument mounting 87
Gamma-radiation monitor with audible warning device, A personal 120
Gardner mobilometer, A mechanical 499
Gas
  evolution from systems irradiated by fast electron beams, A cell for kinetic measurements of 64
  flow through a restriction of variable resistance, Regulator for maintaining a constant 449
  introductor for a vacuum system, A 360
  samples, very small, A method for rapid analysis of 254
  valve, A simple 160
Gaseous discharges, A servo-mechanism for the study of self-extinction of, in cavities in dielectrics 7
Gases, radioactive, A scintillation counter for the assay of 1
Gauge
  Ionization, *see* Ionization gauge(s)
  , McCleod, for measuring a wide range of pressures, A 317
  , Pirani, for operation up to a pressure of 10 mm of mercury, A 181
  , radioactive ionization, and its application to the measurement of latent heat of vaporization, A 376
  , Ultrasonic thickness 455
Gauging, pneumatic, The application of, to high precision linear measurement 388
Geiger
  counter mounting, A two-circle 241
  -counter X-ray powder diffractometer with automatic recording, A monitored 204
  -Müller counter, An oxygen-quenched 185
  tube 327
  tubes 510
Generator, Low-frequency wave-form 206
Generator, Vibration 39
Germanium junction diode 326
Glass
  , all-, reference electrode for molten salt systems, An 438
  , Laboratory furnace with rotating table for producing conducting 320
  tubing, An illuminator for detecting air lines in 239
Glossary of terms relating to the performance of measuring instruments 168
Grain, Fine, development in xerography 194
Gratings, diffraction, On preparing plastic copies of; an extension to the Merton-N.P.L. process 348
Guard, A simple water failure, for diffusion pumps and condensers 199

Hall coefficient, A simple apparatus for recording the variations of, with temperature 164
Half-wave plates, Composite quarter- and 298

Harwell, Atomic energy research at (*erratum*) 128
Heart pulse amplifier and ratemeter, A 440
Height of water waves in model ship tanks, An ultrasonic apparatus for recording the 91
Helium
  flow counter, An easily constructed 322
  liquefier and cryostat, An improved 148
  , liquid, A simple desorption system for obtaining temperatures above that of 31
High-pressure diffusion cloud chamber in a pulsed magnetic field, A 302
High temperature, *see* Temperature, high
High-voltage unit, Portable 326
Hinges, Angle-spring 245
Holder, object for microscopic measurements, An 35
Horology and instrument technology, Courses in 368
Housing, Scintillation counter 246
Humidity, An apparatus for producing air of controlled relative, for hygrometer calibration and testing 273
Humidity, The effect of, on the stability of inductance standards 75
Hydrogen, Preparation and maintenance of spherical metal electrodes in 400
Hygrometer calibration and testing, An apparatus for producing air of controlled relative humidity for 273
Hygrometer, capacitance-resistance, A 36, 284
Hysteresis loops, An instrument for the automatic recording of 265

Illumination control, A beam splitter with 202
Illumination unit, A cloud chamber 324
Illuminator for detecting air lines in glass tubing, An 239
Impedance plotter, Automatic 165
Impedance, pulse, A simple bridge circuit for the accurate measurement of 364
Indicator, An electrical, for a mercury U-tube manometer 412
Indium foil counter for the measurement of neutron flux, An 404
Inductance standards, The effect of humidity on the stability of 75
Induction head, nuclear, A sensitive and stable 260
Information, binary-coded, The use of octal numbers for recording 405
Infra-red spectrometer as a non-dispersive instrument, The 283
Injection phenomena in the Birmingham proton synchrotron, An analysis of 102
Injection system of the Birmingham proton synchrotron, The principles and apparatus for the 52
Institute of Physics,
  Elections to The 88, 167, 248, 367, 456
  Publications of The 167
  The 328
Instrumentation, Exhibition of 456
Instrument
  calibration and performance, The language of 249
  for measuring respiratory rates and volumes, An 154
  for the automatic recording of hysteresis loops 265
  mounting, Galvanometers for 87
  switches, Precision 508
  technology, Course in horology and 368
Instruments,
  British scientific, Directory and handbook of 168
  British scientific, Permanent display of 128
  measuring, Glossary of terms relating to the performance of 168
Insulating liquids, Rotating electrode unit for measurements of the electric strength of 163
Interference-filter reflectometer 366
Interferograms, Solarization technique for 406
Interferometer, A Kösters-type 478
Interferometry, optical, Mercury 198 light source for 327
Interrupter, A light, of continuously variable on-off ratio 281
Interval timer, A simple 84
Ionization
  chamber, A high pressure methane 276
  gauge control circuit, An improved 488
Ionization—*continued*
  gauge, radioactive, and its application to the measurement o latent heat of vaporization, A 376
  gauges, A simple air lock for 83
Ion-source, An improved design of radio-frequency 447
Isothermal micro-calorimeter, An 58

Joining tungsten wire to other metals, A note on 505
Joint extractor, conical ground 400
Journal of Fluid Mechanics 456
Journal of the British Nuclear Energy Conference 167

Kinetic measurements of gas evolution from systems irradiated b fast electron beams, A cell for 64

Laboratory, Simple equipment for a small low-temperature 42
Laminated copper, A method of preparing 33
Lamps, Hollow cathode 127
Lantern slides 407
Latent heat of vaporization, A radio-active ionization gauge an its application to the measurement of 376
Leak detector, A simple vacuum, using a radio-frequency mas spectrometer 392
Leak detector, The omegatron as a 269
Lenses, objective, Quantitative application of the Foucault test t 506
Lenses, plastic, Large liquid-filled 123
Lesions, controlled, An apparatus for the production of, in biological tissue without stimulation 450
Lifetimes, short, A fast coincidence system for the measurement o 429
Light
  interrupter of continuously variable on-off ratio, A 281
  , polarized, The use of, for the measurement of small angula displacements 20
  " -profile" method, The adaptation of a metallurgical microscope to the 504
  source for optical interferometry, Mercury 198 327
Linear movements, An adaptable mechanism for converting rotar motion into a succession of 35, 245
Liquefier and cryostat, An improved helium 148
Liquid level regulator for replenishing cold traps, A 322
Liquid scintillator containing nitrogen 126
Liquids,
  corrosive, A control valve for 244
  insulating, Rotating electrode unit for measurements of the electric strength of 163
  method for comparing ultrasonic velocities in solids and, using a spectrometer, A 361
  simple, small dielectric test cell for, A 315
Low-temperature laboratory, Simple equipment for a small 420
Luminances of fluorescent powders, Photometer for assessing relative 37

Machine vice 407
Magnetically operated vacuum valve, A 34
Magnetic
  analyser for high energy particles, A 151
  field, pulsed, A high-pressure diffusion cloud chamber in a 302
  resonance, Symposium on 328
  spectrometer, A 129
  tape, Eight-channel recording on a $\frac{1}{4}$ in., with a stationary-tape playback 415
Magnetism and magnetic materials, Conference on 167
Magnetometer, torque, Some aspects in the design of a 5
Magnetrons, Tunable X-band 407
Magnets, Demagnetization of, due to contact with ferromagnetic bodies 311
Magnifying powers of optical instruments, The 503

anometer, A sensitive null-point 161
anometer, mercury U-tube, An electrical indicator for a 412
anostat, A sensitive 82
anufacturers' publications
  Capacitors 511
  Cast aluminium alloys 166
  Chemical laboratory apparatus 511
  Earth loop resistance tester 325
  Electrical engineering data sheets 166, 511
  Electrical testing equipment 511
  Electric surface heaters 511
  Electronic devices 208
  Electronic instruments 166
  Electronic measuring instruments 166
  Electron microscopes 511
  Enlarging lenses 511
  Eyepiece camera for photomicrography 325
  Fuel hose 511
  Gamma-radiation survey equipment 511
  Guide to screw thread forms 325
  High-speed, serial digit computer 325
  High temperature alloys 208
  High-vacuum, melting and pouring induction furnaces 325
  High vacuum rotary piston pumps 511
  Industrial radiography 325
  Iris diaphragm 511
  Jointing compounds 511
  Laboratory apparatus 511
  Lens tissue and filter paper 166
  Lubrication using molybdenum disulphide 208
  Magnifiers 325
  Metal and alloys 511
  Microwave equipment 208
  Miniature electrical instruments 166
  Miniature precision commutator 511
  Miniature precision potentiometers 511
  Multi-purpose spot-follower recorder 511
  Nickel alloys by powder metallurgy 325
  Noble metal thermocouples 208
  Nuclear instruments 511
  Optical glass 208
  Optical instruments 325
  Potentiometers 511
  Proximity meter 325
  Resistance thermometer 511
  Screw gauge and profile projection lenses 325
  Servo and remote control elements 511
  Solenoid valves 166
  Square pulse generator 511
  Standard parts for jigs and fixtures 511
  Switches and a.c.–d.c. converter 325
  Tube manufacturing practice and specifications 511
  Tungsten, molybdenum and special wires 325
  Vacuum impregnation control equipment 511
  Waveguide components 208
  X-ray apparatus 511
Mass spectrometer, radio-frequency, A simple vacuum leak detector using a 392
McCleod gauge for measuring a wide range of pressures, A 317
Measurement and control, Some principles of 457
Measurement, high precision linear, The application of pneumatic gauging to 388
Measurements, Fine 369
Mechanism, A large optical slit, employing spring movements 169
Mechanism for converting rotary motion into a succession of linear movements, An adaptable 35, 245
Mechanisms, An international bibliography of 168
Megohmmeter, A logarithmic 158
Membrane, interferometric microrespirometer, A constant-volume 263
Mercury 198 light source for optical interferometry 327
Mercury U-tube manometer, An electrical indicator for a 412
Message register, A reversible 505
Metallizing a betatron toroid by vacuum deposition, On internally 445
Metals, A note on joining tungsten wire to other 505
Meteorological Office annual report for 1954–55 128
Methane ionization chamber, A high pressure 276
Merton–N.P.L. process, an extension to the, On preparing plastic copies of diffraction gratings; 348
Micro-calorimeter, An isothermal 58
Microdensitometer, Automatic recording 127
Micro-focus X-ray units, Miniature diffraction cameras for 161
Micromanipulator 87
Micromanometer designed for recording, A 402
Microprojector 508
Microradiography, Symposium on X-ray microscopy and 128
Microrespirometer, A constant-volume, membrane, interferometric 263
Microscope
  , metallurgical, The adaptation of a, to the "light-profile" method 504
  photoelectric, for the measurement of linear scales, A 341
  vernier 454
Microscopes, interference, Fringe spacing in 236, 507
Microscopic measurements, An object holder for 35
Microscopy and microradiography, X-ray, Symposium on 128
Microspectrometer, A double-beam 491
Microswitch 37
Microwave
  amplitude stabilizer, A 363
  attenuator, A secondary 448
  thermistor calorimeter, A 353
Miniature diffraction cameras for microfocus X-ray units 161
Minority carrier lifetime test set 287
Mirrors, galvanometer, Adhesives for 362 (*erratum*) 512
Mixtures, Calorimetry by the method of 211
Mobilometer, A mechanical Gardner 499
Moisture meter 207
Molecular spectroscopy, Documentation of (D.M.S. system) 88
Monitor
  β–γ radiation, A portable 83
  circuit, A simple, for a spectrographic a.c. arc source 226
  , γ-radiation, A personal, with audible warning device 120
Motors, small synchronous, Phasing device for 319
Mount, A flexible, for specimens in single crystal and powder X-ray cameras 318
Mounting, A two-circle Geiger counter 241
Mounting, instrument, Galvanometers for 87
Movement
  , A parallel-spring cross-, for an optical bench 279
  of dosage measuring or similar equipment to indicated positions, A remote control apparatus for the 191
  , transfer of, into a vacuum by means of twisting a copper tube 200
Movements, spring, A large optical slit mechanism employing 169
Movements, spring, Some parasitic deflexions in parallel 11
Multi-circuit sequence timer 326

Narrow-band filters for use in the ultra-violet spectral region 286
National Physical Laboratory, Recent work at the 367
Neutron flux, An indium foil counter for the measurement of 404
Nitrogen, A liquid scintillator containing 126
Noise generator, "White" 165
Nuclear
  emulsion layers, An automatic device for fixing thick 296
  emulsion stacks, An alinement and co-ordinate system for 381
  emulsions, An automatic scanner for 135
  induction head, A sensitive and stable 260
  reactor data 88
  reactors, Catalogue of 167
  reactors, Conference on the physics of 248
Nuclear Engineering 408
Nuclear Physics 167
Nuclear Power 288

Object holder for microscopic measurements, An 35
Octal numbers for recording binary-coded information, The use of 405
Omegatron as a leak detector, The 269
Optical
  bench, A parallel-spring cross-movement for an 279
  density of smoke in a chimney, Measurement of the 495
  diffraction patterns, Apparatus for the electronic presentation of 24
  instruments, The magnifying powers of 503
  pulse-counting systems, A simple direction-sensitive phototransistor circuit for use in 483
  slit mechanism, A large, employing spring movements 169
Oscillator for very low frequencies 286
Oscillator with sine- and square-wave output 206
Oscilloscope
  cathode-ray, beam brightening device for transient recordings, An automatic 203
  , Cathode-ray, for twenty-four traces 166
  Miniature light-weight 327
  Precision pulse 165
  Wide-band, two-channel 38
Oscilloscopes 39
Output resistance of a switch-dial potential divider, The 451
Oxygen-quenched Geiger–Müller counter, A 185

Paramagnetic oxygen meter, Two designs for a 176
Particles, high energy, A magnetic analyser for 151
Patents abridgements, Publication of 456
Pen-recorder chart analyser, A semi-automatic 228
Performance, The language of instrument calibration and 249
Petrol, An X-ray absorptiometer for the determination of tetraethyl lead in 222
Phase-sensitive voltmeters 37
Phasing device for small synchronous motors 319
Philpot, Mr. A. J., Retirement of 248
Photoelectric
  colorimeter 509
  microscope for the measurement of linear scales, A 341
  transducers and electronic tachometer 327
Photometer circuit, A wide range, recording, logarithmic 69
Photometer for assessing relative luminances of fluorescent powders 37
Photomultiplier characteristics, Modifications of, by dynode voltage control 163
Photomultiplier construction, An improved 323
Photomultipliers, On the reduction of the dark current of 476
Phototransistor 286
Phototransistor circuit for use in optical pulse-counting systems, A simple direction-sensitive 483
Physical Society's annual exhibition of scientific instruments and apparatus, The 128
Physical Society's Exhibition—London, 1956 289
Physics in Medicine and Biology 512
Pile radiation, A calorimeter for measuring energy absorption from 46
Pirani gauge for operation up to a pressure of 10 mm of mercury, A 181
Plastic copies of diffraction gratings, On preparing; an extension to the Merton–N.P.L. process 348
Plastic lenses, Large liquid-filled 123
Plotter, Automatic impedance 165
Pneumatic gauging, The application of, to high precision linear measurement 388
Polarized light for the measurement of small angular displacements, The use of 20
Polarograph, An improvement to a 87
Polymers, high, Dynamometer for tensile testing of 432
Positioning a specimen relative to an X-ray beam, A simple visual method of accurately 239
Potential divider, A switch-dial 196
Potential divider, The output resistance of a switch-dial 451
Potentiometer, Electrothermal 407
Potentiometers, Miniature 247
Powder studies, A versatile X-ray diffractometer for single-cryst and 138
Power unit, E.H.T. 39
Precipitator, electrostatic, Application of the, to the measuremen of radioactive aerosols 142
Pressure
  high, methane ionization chamber, A 276
  measurements in an over-compression cloud chamber, Tem perature and 507
  of 10 mm of mercury, A Pirani gauge for operation up to a 18
  recorder, A miniature eight-channel 383
  transducer, Zirconate 455
Prism, A simple method of controlling the temperature of a 12
Probe apparatus for measuring resistivity, A four-point 85
Process streams, An automatic analyser of uranium content in 46
Protection device, A furnace over-temperature 201
Psychrometric data from dry- and wet-bulb recorders, The direc evaluation of 199
Pulse
  -counting systems, optical, A simple direction-sensitive phot transistor circuit for use in 483
  generator, Square 407
  -height analyser, An input ampifier for a 187
  height analyser, A simple differential 257
  impedance, A simple bridge circuit for the accurate measuremen of 364
  oscilloscope, Precision 165
  technique, Coulometric titrations using a 323
Pumps, diffusion, and condensers, A simple water failure guard fo 199
Pump, Vacuum 510
Pyrometer, Recording thermocouple 510

Quarter- and half-wave plates, Composite 298

Radiation
  monitor, A portable β–γ 83
  monitor, γ-, A personal, with audible warning device 120
  pile, A calorimeter for measuring energy absorption from 46
  solar, An instrument for measuring absorptivities for 356
Radii of curvature, Precision measurement of small 487
Radioactive
  aerosols, Application of the electrostatic precipitator to the measurement of 142
  gases, A scintillation counter for the assay of 1
  ionization gauge and its application to the measurement of laten heat of vaporization, A 376
  materials, A calorimetric method of determining the energy output of 230
  materials, A d.c. arc chamber for 359
Ratemeter, A heart pulse amplifier and 440
Ratemeter, Field 246
Reactor data, Nuclear 88
Reactors, nuclear, Catalogue of 167
Reactors, nuclear, Conference on the physics of 248
Receivers and transmitters, Sound 327
Recorder, electrical, Two-axis 454
Recording, Eight-channel, on a $\frac{1}{4}$ in. magnetic tape with a stationary-tape playback 415
Recording system, The use of a ball-point, on the Dines anemometer 280
Reflectometer, An automatic absolute 317
Reflectometer, Inteference-filter 366
Register, A reversible message 505
Register of British manufacturers 88
Regulator
  A liquid level, for replenishing cold traps 322
  for maintaining a constant gas flow through a restriction of variable resistance 449
  tubes, voltage, Fixed and variable 326

Relay, miniature 207
Relay-operated timer, A simple 33
Remote control apparatus for the movement of dosage measuring or similar equipment to indicated positions, A 191
Report of a conference on engineering fastenings 168
Resistance values, A simple method for the measurement of high 486
Resistivity, A four-point probe apparatus for measuring 85
Resonance, Measurement of the damping of metal bar specimens in mechanical 123
Respiratory rates and volumes, An instrument for measuring 154
Restriction of variable resistance, Regulator for maintaining a constant gas flow through a 449
Rock susceptibility meter 207
Rotary motion, An adaptable mechanism for converting, into a succession of linear movements 35, 245

Salinity in estuaries, An instrument for the measurement of 424
Salt systems, molten, An all-glass reference electrode for 438
Scaler, Transistor decade counter and 509
Scales, linear, A photoelectric microscope for the measurement of 341
Scanner for nuclear emulsions, An automatic 135
Scanning mechanism for X-ray diffraction, A simple 391
Schlieren system, A wide range 29
Scientific instruments, British, Permanent display of 128
Scintillation counter for the assay of radioactive gases, A 1
Scintillation counter housing 246
Scintillator, liquid, containing nitrogen, A 126
Sealing iron, Cellophane 39
Seal, vacuum, A simple demountable, for electrical connexions 402
Sea water analysis, A portable temperature-chlorinity bridge for estuarine investigations and 329
Semi-conducting antimony bolometer, A 338
Servo-mechanism for the study of self-extinction of gaseous discharges in cavities in dielectrics, A 7
Servomechanisms and related subjects, Bibliography of information on 168
Shrinkage of textile yarns, An instrument for the continuous measurement of 394
Single crystal and powder studies, A versatile X-ray diffractometer for 138
Single crystal X-ray work, An attachment for high temperature 89
Single crystals of appreciable vapour pressure, A high-temperature microthermostat for X-ray studies on 386
Slides, Lantern 407
Slit mechanism, A large optical, employing spring movements 169
Smoke in a chimney, Measurement of the optical density of 495
Solarization technique for interferograms 406
Solar radiation, An instrument for measuring absorptivities for 356
Solids and liquids, A method for comparing ultrasonic velocities in, using a spectrometer 361
Solubility cell or reaction vessel for a Beckman quartz spectrophotometer, A constant temperature 27
Sound receivers and transmitters 327
Source
  , radio-frequency ion-, An improved design of 447
  , Spectrographic a.c. arc, A simple monitor circuit for a 226
  units, Arc and spark stands and 39
Soviet Physics 40
Specimen chamber for an X-ray diffractometer, A precision high-temperature 107
Specimen spinner for transmission and reflexion X-ray diffraction, A dual-purpose 281
Spectrographic a.c. arc source, A simple monitor circuit for a 226
Spectrometer,
  A method of comparing ultrasonic velocities in solids and liquids using a 361
  infra-red, as a non-dispersive instrument, The 283
  magnetic, A 129
  wavelength discrimination, A 217
Spectrophotometer, Beckman quartz, A constant temperature solubility cell or reaction vessel for a 27
Spectroscopists, Electronics for 128
Spectroscopy, molecular, Documentation of (D.M.S. system) 88
Spring movements, A large optical slit mechanism employing 169
Spring movements, parallel, Some parasitic deflexions in 11
Springs, sensitive, Fundamental behaviour of 78
Stabilizer, A microwave amplitude 363
Stacks, nuclear emulsion, An alinement and co-ordinate system for 381
Standards, inductance, The effect of humidity on the stability of 75
Stands, Arc and spark, and source units 39
Stand, X-ray camera, A simple universal 82
Storing mechanically fragile specimens for examination, A method of 451
Stressing unit, An automatic electromechanical, for creep and fatigue testing 409
Stroboscope 287
Stroboscopic light, Calibration of a 204
Susceptibility meter, Rock 207
Suspensions, A continuous-flow rotational viscometer for use with downward-settling 110
Switch controller, Vacuum 509
Switch-dial potential divider, A 196
Switches, Precision instrument 508
Symposium on magnetic resonance 328
Symposium on X-ray microscopy and microradiography 128
Synchrotron, Birmingham proton,
  An analysis of injection phenomena in the 102
  The principles and apparatus of the injection system of the 52

Tachometer, Electronic 247
Tachometer, electronic, Photoelectric transducers and 327
Tangents, Device for measurement of 506
Tanks, An ultrasonic apparatus for recording the height of water waves in model ship 91
Tape, ¼ in. magnetic, Eight-channel recording on, with a stationary-tape playback 415
Tapered plug vacuum valve, A 283
Tap for continuous operation, A two-way 31
Temperature
  and pressure measurements in an over-compression cloud chamber 507
  calibration of a high-temperature X-ray diffraction camera, The 41
  -chlorinity bridge for estuarine investigations and sea water analysis, A portable 329
  controller, Electronic 206
  controller for an electric furnace 365
  cycle controller 494
  , high-, single-crystal X-ray work, An attachment for 89
  , high-, specimen chamber for an X-ray diffractometer, A precision 107
  high-, X-ray cameras, A window material for 445
  , low-, laboratory, Simple equipment for a small 420
  of a prism, A simple method of controlling the 125
  , over-, protection device, A furnace 201
  , variation of Hall coefficient with, A simple apparatus for recording 164
Temperatures above that of liquid helium, A simple desorption system for obtaining 31
Tensile testing of high polymers, Dynamometer for 432
Terms used in a.c. power system studies 248
Test meter, Multirange, using transistor amplifier 38
Test set, Minority carrier lifetime 287
Tetraethyl lead in petrol, An X-ray absorptionmeter for the determination of 222
Textile yarns, An instrument for the continuous measurement of shrinkage of 394
Thermistor calorimeter, A microwave 353
Thermistors, The stability of 16
Thermocouple pyrometer, Recording 510

Thermometer, Electronic 326
Thermostat, micro-, A high-temperature, for X-ray studies on single crystals of appreciable vapour pressure 386
Thickness, film, The measurement of, with a pneumatic hypodermic needle mechanism 333
Thickness gauge, Ultrasonic 455
Thrust, A transducer for the sequential measurement of two levels of 321
Thyratron index and time-marking unit, A 32
Timer,
  , internal, A simple 84
  Multi-circuit sequence 326
  simple relay-operated, A 33
Time spread, Transit, in electron multipliers 36
Tissue, biological, An apparatus for the production of controlled lesions in, without stimulation 450
Titration, automatic potentiometric, Devices for 92
Titrations, Coulometric, using a pulse technique 323
Torque magnetometer, Some aspects in the design of a 5
Transducer
  for the sequential measurement of two levels of thrust, A 321
  of simple design, A mechanical-electrical 315
  , pressure, Zirconate 455
Transducers, Barium titanate 287
Transducers, Photoelectric, and electronic tachometer 327
Transient recordings, An automatic cathode-ray oscilloscope beam brightening device for 203
Transistor
  amplifier, Multi range test meter using 38
  decade counter and scaler 509
  test apparatus 246
Transit time spread in electron multipliers 36
Transmitters, Sound receivers and 327
Traps, Conduction-cooled vapour 245
Tube, proportional counter, for X-ray diffraction analysis, A 209
Tungsten wire, A note on joining to other metals 505

Ultrasonic
  apparatus for recording the height of water waves in model ship tanks, An 91
  thickness gauge 455
  velocities in solids and liquids, A method for comparing, using a spectrometer 361
Ultra-violet spectral region, Narrow-band filters for use in the 286
Union, Adaptation of a gas and water, to high vacuum circuits 279
Uranium content in process streams, An automatic analyser of 467
User specification for high-temperature X-ray powder diffraction cameras 288

Vacuum
  circuits, high, Adaptation of a gas and water union to 279
  deposition, On internally metallizing a betatron toroid by 445
  , high, A mercury cut-off for transferring gas at atmospheric pressure into a 318
  , high, magnetic mercury cut-off, A 243
  induction furnace, A laboratory scale chill-casting 22
  leak detector, A simple, using a radio-frequency mass spectrometer 392
  plate-camera of large capacity, A new 465
  pump 510
  seal, A simple demountable, for electrical connexions 402
  switch controller 509
  system, A gas introductor for a 360
  , Transfer of movement into a, by means of twisting a copper tube 200
  valve, *see* Valve, vacuum
Valve
  for corrosive liquids, A control 244
Valve—*continued*
  , gas, A simple 160
  , vacuum, A magnetically operated 34
  , vacuum, A modified flap-type 361
  , vacuum, A tapered plug 283
Vapour
  pressure curve of water, An electronic analogue of the saturated 436
  pressures, appreciable, A high-temperature micro-thermostat for studies on single crystals of 386
  traps, Conduction-cooled 245
Velocities, ultrasonic, in solids and liquids, A method of comparing using a spectrometer 361
Vernier microscope 454
Vibrating contacts, The measurement of frictional forces at 213
Vibration generator 39
Vice, Machine 407
Viscometer, A continuous-flow rotational, for use with downward-settling suspensions 110
Voltage regulator tubes, Fixed and variable 326
Voltmeter, d.c., of high resistance 206
Voltmeters, Phase-sensitive 37

Water
  An electronic analogue of the saturated vapour pressure curve of 436
  -driven device for filling, aerating and agitating baths, A 320
  failure guard for diffusion pumps and condensers, A simple 199
  vapour recorder for equatorial use, A 132
Wave-form generator, Low-frequency 206
Wavelength discrimination spectrometer, A 217
Waves, water, in model ship tanks, An ultrasonic apparatus for recording the height of 91
Wet-bulb recorders, The direct evaluation of psychrometric data from dry- and 199
"White" noise generator 165
Window material for high-temperature X-ray cameras, A 445
Wire, tungsten, A note on joining, to other metals 505

Xerography, Fine grain development in 194
X-ray
  absorptiometer for the determination of tetraethyl lead in petrol, An 222
  beam, A simple visual method of accurately positioning a specimen relative to an 239
  camera stand, A simple universal 82
  cameras, A flexible mount for specimens in single crystal and powder 318
  cameras, high-temperature, A window material for 445
  diffraction analysis, A proportional counter tube for 209
  diffraction camera, The temperature calibration of a high-temperature 41
  diffraction, dual purpose specimen spinner for transmission and reflexion, A 281
  diffraction, simple scanning mechanism for, A 391
  diffraction unit, Small angle 66
  diffractometer, A precision high-temperature specimen chamber for an 107
  diffractometer, for single-crystal and powder studies, A versatile 138
  fluorescence analysis, Attachment for 37
  microscopy and microradiography, Symposium on 128
  powder diffraction cameras, User specification for high-temperature 288
  powder diffraction patterns, Errors in the A.S.T.M. Index of 86
  powder diffractometer, A monitored Geiger-counter, with automatic recording 204
  proportional counters, Some notes on the design and performance of 96

X-ray—*continued*
studies on single crystals of appreciable vapour pressure, A high-temperature micro-thermostat for 386
therapy, Exhibition of supervoltage machines for 40
units, micro-focus, Miniature diffraction cameras for 161
work, An attachment for high-temperature single-crystal 89

Yarns, textile, An instrument for the continuous measurement of shrinkage of 394
Yawmeter, A remotely-controlled traversing, for boundary-layer exploration 173

Zirconate pressure transducer 455

AUTHORS

Adams, J. R., Fine measurements 369
Allan, H. R., and N. Sarma, An improved design of radio-frequency ion source 447
Allen, K. R., F. Ashworth and G. Siddall, On internally metallizing a betatron toroid by vacuum deposition 445
Allenden, D., and I. W. Collip, A personal γ-radiation monitor with audible warning device 120
Alexander, E., and I. T. Steinberger, Laboratory furnace with rotating table for producing conducting glass 320
Alexander, T. G., *see under* Ford, T. F.
Ambrose, D., and P. H. Bigg, Correction of millimetre mercury barometers 126
Amphlett, C. B., and T. F. Williams, A cell for kinetic measurements of gas evolution from systems irradiated by fast electron beams 64
Anderson, A. R., and R. J. Waite, A calorimeter for measuring energy absorption from pile radiation 46
Anderson, S. P., *see under* Sucksmith, W.
Arregger, C. E., Solarization technique for interferograms 406
Aruja, E., A flexible mount for specimens in single crystal and powder X-ray cameras 318
Ashworth, F., *see under* Allen, K. R.
Audran, R., and D. T. R. Dighton, Devices for automatic potentiometric titration 92

Bane, W. T., and D. L. A. Barber, A simple direction-sensitive phototransistor circuit for use in optical pulse-counting systems 483
Barber, D. L. A., *see under* Bane, W. T.
Bardócz, Á., and Á. Klatmányi, A cloud chamber illumination unit 324
Barnes, J. C., Temperature cycle controller 494
Barrow, C., A simple air lock for ionization gauges 83
Bartley, A. J., The use of polarized light for the measurement of small angular displacements 20
Barton, J. C., A "hodoscoped" cosmic-ray recorder 308
Eight-channel recording on $\frac{1}{4}$ in. magnetic tape with a stationary-tape playback 415
Batson, A. P., P. N. Cooper and L. Riddiford, A high-pressure diffusion cloud chamber in a pulsed magnetic field 302
Baxter, S., and P. D. Wilmot, A simple, small dielectric test cell for liquids 315
Bazzard, G. H., *see under* Spencer, C. W.
Beck, A., The stability of thermistors 16
Bell, R. L., The omegatron as a leak detector 269
Berger, B., A modified bridge earthing device 184
Bergstedt, B. A., Application of the electrostatic precipitator to the measurement of radioactive aerosols 142
Berry, J. P., A sensitive null-point manometer 161
Bestelink, P. N., and D. R. Holmes, A dual-purpose specimen spinner for transmission and reflexion X-ray diffraction 281
Beynon, J. H., and G. R. Nicholson, A radioactive ionization gauge and its application to the measurement of latent heat of vaporization 376
Bhalla, M. S., *see under* Hariharan, P.
Bigg, P. H., *see under* Ambrose, D.
Birks, F. T., and R. P. Thorne, A d.c. arc chamber for radioactive materials 359
Bisby, H., L. H. Brown and D. R. Chapman, An automatic analyser of uranium content in process streams 467
Bockris, J. O'M., B. E. Conway and W. Mehl, Preparation and maintenance of spherical metal electrodes in hydrogen 400
Bockris, J. O'M., G. J. Hills, D. Inman and L. Young, An all-glass reference electrode for molten salt systems 438
Bones, R., A two-circle Geiger counter mounting 241
Bower, J. C., *see under* Hadley, D. W.
Bower, J. C., *see under* Walker, J.
Brand, J. A., and H. J. Goldschmidt, The temperature calibration of a high-temperature X-ray diffraction camera 41
Brewer, D. F., and D. O. Edwards, An improved helium liquefier and cryostat 148
Brody, T. P., A light interrupter of continuously variable on-off ratio 281
Broom, R. F., and A. C. Rose-Innes, Simple equipment for a small low-temperature laboratory 420
Broom, R. F., *see under* Rose-Innes, A. C.
Brown, J. F., and R. J. Weir, An X-ray absorptiometer for the determination of tetraethyl lead in petrol 222
Brown, L. H., *see under* Bisby, H.
Bruce, C. F., A Kösters-type interferometer 478
Bryer, D. W., A remotely-controlled traversing yawmeter for boundary-layer exploration 173
Buck, H. M., A modified flap-type vacuum valve 361
Burt, R., and G. J. Minkoff, The infra-red spectrometer as a non-dispersive instrument 283

Campe, W. K., *see under* Richards, E. A.
Cassell, A. D., and D. A. Hockly, Adaptation of a gas and water union to high vacuum circuits 279
Chackett, K. F., P. Reasbeck and D. G. Tuck, A note on joining tungsten wire to other metals 505
Chapman, D. R., *see under* Bisby, H.
Childs, W. H. J., Composite quarter- and half-wave plates 298
Christy, R. W., Temperature controller for an electric furnace 365
Clark, J. S., and A. H. Cook, A photoelectric microscope for the measurement of linear scales 341
Clothier, W. K., A switch-dial potential divider 196
Clouston, J. G., A transducer for the sequential measurement of two levels of thrust 321
Coales, J. F., Some principles of measurement and control 457
Coe, R. F., *see under* Ramm, C. A.
Cohen, E. A., The use of a ball-point recording system on the Dines anemometer 280
Collinge, B., A. W. Merrison and D. Eccleshall, A fast multiple coincidence circuit 72
Collip, I. W., *see under* Allenden, D.
Conway, B. E., *see under* Bockris, J. O'M.
Cook, A. H., *see under* Clark, J. S.
Cooper, P. N., *see under* Batson, A. P.
Cram, L. A., An apparatus for producing air of controlled relative humidity for hygrometer calibration and testing 273
Craw, D. A., and W. G. Henry, A laboratory scale chill-casting vacuum induction furnace 22
Cutting, C. L., A. C. Jason and J. L. Wood, A capacitance-resistance hygrometer 36, 284

Davie, O. H., An automatic cathode-ray oscilloscope beam brightening device for transient recordings 203
Davies, D. A., The generation of accurate cylinders 501
Deeley, E. M., Modifications of photomultiplier characteristics by dynode voltage control 163
Dent, L. S., and H. F. W. Taylor, An attachment for high-temperature single-crystal X-ray work 89
Devanathan, M. A. V., and Q. Fernando, Coulometric titrations using a pulse technique 323
Dew, G. D., On preparing plastic copies of diffraction gratings; an extension to the Merton–N.P.L. process 348
Dighton, D. T. R., and W. G. Waters, Phasing device for small synchronous motors 319
Dighton, D. T. R., *see under* Audran, R.

Eccleshall, D., *see under* Collinge, B.
Edwards, D. O., *see under* Brewer, D. F.
Ellis, R. A. E., K. W. Hillier and A. B. Thompson, An instrument for the continuous measurement of shrinkage of textile yarns 394
Emmerson, B. W., and S. P. Newbery, A portable β–γ radiation monitor 83
Evans, J. C., and I. G. Morgan, The application of pneumatic gauging to high-precision linear measurement 388
Eveson, G. F., and E. W. Hall, A continuous-flow rotational viscometer for use with downward-settling suspensions 110

Farley, F. J. M., A high pressure methane ionization chamber 276
Fernando, Q., *see under* Devanathan, M. A. V.
Finean, J. B., Miniature diffraction cameras for micro-focus X-ray units 161
Fochs, P. D., *see under* Holmes, P. J.
Folkierski, A., An input amplifier for a pulse-height analyser 187
Ford, L. H., *see under* Rayner, G. H.
Ford, T. F., and T. G. Alexander, Calibration of a stroboscopic light 204
Forshaw, C. R., A wavelength discrimination spectrometer 217
Forsyth, P. M., and R. W. G. Hunt, A beam splitter with illumination control 202
Fray, J. S., and M. F. Kimmitt, A microwave amplitude stabilizer 363
Fray, S. J., *see under* Roberts, L. M.
Fuller, J., A simple gas valve 160
Fuschillo, N., and J. Gilvey, A simple demountable vacuum seal for electrical connexions 402

Gall, D. C., and J. D. Watson, An instrument for the automatic recording of hysteresis loops 265
Gard, J. A., Calibration of the specimen tilt device of the EM-3 electron microscope 307
Gasson, D. B., A four-point probe apparatus for measuring resistivity 85
Gates, J. W., Fringe spacing in interference microscopes 507
Gibson, W. M., *see under* Prowse, D. J.
Gillham, E. J., A semi-conducting antimony bolometer 338
Gilvey, J., *see under* Fuschillo, N.
Glaister, R. M., A magnetically operated vacuum valve 34
Glew, D. N., and R. E. Robertson, A constant temperature solubility cell or reaction vessel for a Beckman quartz spectrophotometer 27
Goldsack, S. J., and H. B. van der Raay, An automatic scanner for nuclear emulsions 135
Goldschmidt, H. J., *see under* Brand, J. A.
Greenland, K. M., The language of instrument calibration and performance 249
Greenwood, N. N., A mercury cut-off for transferring gas at atmospheric pressure into a high vacuum 318
Grimes, F. A., A two-way tap for continuous operation 31
Grodzinski, P., An adaptable mechanism for converting rotary motion into a succession of linear movements 245
Gugan, D., Simple high-pressure closures and electrodes 160
Gunn, J. B., A simple bridge circuit for the accurate measurement of pulse impedance 364
Gupta, S. R., and G. J. Hills, A precision electrode-less conductance cell for use at audio-frequencies 313

Hadley, D. W., J. C. Bower and J. Walker, Temperature and pressure measurement in an over-compression cloud chamber 507
Hadley, D. W., *see under* Walker, J.
Haggis, G. H., A double-beam microspectrometer 491
Hall, E. W., *see under* Eveson, G. F.
Halliday, J. S., The measurement of frictional forces at vibrating contacts 213
Hamilton, R. J., A portable instrument for respirable dust sampling 395
Hamilton, T. D. S., and G. T. Wright, Transit time spread in electron multipliers 36
Hamon, B. V., A portable temperature-chlorinity bridge for estuarine investigations and sea water analysis 329
Hanson, A. W., and A. Menarry, Apparatus for the electronic presentation of optical diffraction patterns 24
Hariharan, P., Quantitative application of the Foucault test to objective lenses 506
Hariharan, P., and M. S. Bhalla, A logarithmic megohmmeter 155
  An improved ionization gauge control circuit 488
  A wide range, recording, logarithmic photometer circuit 69
Harris, E. J., An easily constructed helium flow counter 322
Harrison, F. W., Some aspects in the design of a torque magnetometer 5
Harriss, V. G., *see under* Rogers, E. C.
Hart, J., and A. G. Mungall, An electrostatic null detector 411
Haul, R. A. W., and E. R. Swart, A high vacuum magnetic mercury cut-off 243
Hawkins, A. E., An electrical indicator for a mercury U-tube manometer 412
  A simple method for the measurement of high resistance values 486
Heathcote, V. A., Conduction-cooled vapour traps 245
Henry, W. G., *see under* Craw, D. A.
Hillier, K. W., *see under* Ellis, R. A. E.
Hills, G. J., *see under* Bockris, J.O'M.
Hills, G. J., *see under* Gupta, S. R.
Hinde, R. M., *see under* Smith, G. W.
Hobbs, D. S., Modifications of photomultiplier characteristics by dynode voltage control 163
Hobson, A., and R. H. Kay, Two designs for a paramagnetic oxygen meter 176
Hockly, D. A., *see under* Cassell, A. D.
Hodkinson, J., A control valve for corrosive liquids 244
Holmes, D. R., *see under* Bestelink, P. N.
Holmes, P. J., and P. D. Fochs, A simple visual method of accurately positioning a specimen relative to an X-ray beam 239
Houghton, G., A simple water failure guard for diffusion pumps and condensers 199
Hughes, J. W., and E. R. Pike, A monitored Geiger-counter X-ray powder diffractometer with automatic recording 204
Hughes, J. W., I. E. Lewis and A. J. C. Wilson, Errors in the A.S.T.M. Index of X-ray diffraction patterns 86
Hunt, R. W. G., *see under* Forsyth, P. M.
Hutchinson, G. W., The use of octal numbers for recording binary-coded information 405

Inman, D., *see under* Bockris, J. O'M.

Jaffe, J. H., and U. Oppenheim, An automatic absolute reflectometer 317
Jason, A. C., *see under* Cutting, C. L.
Jeffree, H., A wide range Schlieren system 29
Jenkin, L. R., A simple relay-operated timer 33

nnings, A. E., and C. E. F. Misso, An improved photomultiplier construction 323
ones, G., and J. B. Warren, A fast coincidence system for the measurement of short lifetimes 429
ones, R. V., A large optical slit mechanism employing spring movements 169
  Angle-spring hinges 245
  A parallel-spring cross-movement for an optical bench 279
ones, R. V., and I. R. Young, Some parasitic deflexions in parallel spring movements 11

arkhanavala, M. D., A simple universal X-ray camera stand 82
aufer, G. E., An apparatus for the production of controlled lesions in biological tissue without stimulation 450
ay, R. H., *see under* Hobson, A.
een, E. F., and P. L. Palmer, Regulator for maintaining a constant gas flow through a restriction of variable resistance 449
elly, J. C., Thin film abrasion tester 240
ennedy, A. J., and R. F. Slade, An automatic electromechanical stressing unit for creep and fatigue testing 409
immitt, M. F., *see under* Fray, S. J.
ing, A. R., Device for measurement of tangents 506
latsmányi, Á., *see under* Bardócz, Á.

ang, A. R., A versatile X-ray diffractometer for single-crystal and powder studies 138
  Some notes on the design and performance of X-ray proportional counters 96
eck, J. H., and C. S. Martin, A Pirani gauge for operation up to a pressure of 10 mm of mercury 181
ewis, H. E., and O. C. J. Lippold, A method for rapid analysis of very small gas samples 254
ewis, I. E., *see under* Hughes, J. W.
ilburne, M. T., and D. Shipley, A simple interval timer 84
ippold, O. C. J., *see under* Lewis, H. E.
ittlewood, A., Measurement of the optical density of smoke in a chimney 495
ong, I. F., The direct evaluation of psychrometric data from dry- and wet-bulb recorders 199
ovati, A., and H. Tyrén, A magnetic analyser for high energy particles 151
oveless, F. C., *see under* Pierson, D. H.
ucas, L. N. D., and P. B. Sewell, A new vacuum plate-camera of large capacity 465

MacDowall, J., A capacitance-resistance hygrometer 284
Maddock, A. J., The Physical Society's Exhibition—London, 1956 289
Manzotti, M., A mechanical-electrical transducer of simple design 314
Marsh, B. B., and P. M. Nottingham, A simple rotary film evaporator 446
Martin, C. S., *see under* Leck, J. H.
Mathai, A. O., *see under* Sreekantath, G. M.
McCaig, M., Demagnetization of magnets due to contact with ferromagnetic bodies 311
McKeown, P. J. A., A high-temperature micro-thermostat for X-ray studies on single crystals of appreciable vapour pressure 386
Mehl, W., *see under* Bockris, J. O'M.
Menarry, A., *see under* Hanson, A. W.
Merrison, A. W., *see under* Collinge, B.
Metcalfe, K. A., and R. J. Wright, Fine grain development in xerography 194
Minkoff, G. J., *see under* Burt, R.
Misso, C. E. F., *see under* Jennings, A. E.
Moore, A., *see under* Williamson, G. K.
Moore, H. R., A tapered plug vacuum valve 282
Morgan, I. G., *see under* Evans, J. C.
Morrison, R. B., A thyratron index and time-marking unit 32
Morrison, S. J., and S. M. Phillipson, An illuminator for detecting air lines in glass tubing 239
Mungall, A. G., *see under* Hart, J.
Mykura, H., The adaptation of a metallurgical microscope to the "light-profile" method 504

Náray, Zs., On the reduction of the dark current of photomultipliers 476
Nelson, H. M., and G. A. Parker, A miniature eight-channel pressure recorder 383
Nelson, K., A method of preparing laminated copper 33
Newbery, S. P., *see under* Emmerson, B. W.
Newman, R. J., A furnace over-temperature protection device 201
Nicholson, G. R., *see under* Beynon, J. H.
Nisbet, W., An instrument for measuring respiratory rates and volumes 154
Norris, K. P., A simple method of controlling the temperature of a prism 125
Nottingham, P. M., *see under* Marsh, B. B.

Oppenheim, U., *see under* Jaffe, J. H.

Page, E. B., *see under* Rogers, E. C.
Palmer, P. L., *see under* Keen, E. F.
Park, E. C., A simple differential pulse height analyser 257
Parker, G. A., *see under* Nelson, H. M.
Payne, A. R., and J. F. Smith, Dynamometer for tensile testing of high polymers 432
Peirson, D. H., and F. C. Loveless, An indium foil counter for the measurement of neutron flux 404
Perry, B. J., and N. H. Pierce, A remote control apparatus for the movement of dosage measuring or similar equipment to indicated positions 191
Phillips, G., *see under* Richards, E. A.
Phillipson, S. M., *see under* Morrison, S. J.
Pierce, N. H., *see under* Perry, B. J.
Pike, E. R., *see under* Hughes, J. W.
Plester, D. W., S. E. Rogers and A. R. Ubbelohde, Calorimetry by the method of mixtures 211
Powell, A., and K. H. Stark, Rotating electrode unit for measurements of the electric strength of insulating liquids 163
Prescott, J. R., A liquid scintillator containing nitrogen 126
Prime, H. A., A secondary microwave attenuator 448
Probyn, H. C., A liquid level regulator for replenishing cold traps 322
Provan, A. G., B. A. Shaw and G. I. Williams, A window material for high temperature X-ray cameras 445
Prowse, D. J., and W. M. Gibson, A magnetic spectrometer 129
Pursey, H., and E. C. Pyatt, Measurement of the damping of metal bar specimens in mechanical resonance 123
Putley, E. H., A simple apparatus for recording the variation of Hall coefficient with temperature 164
Pyatt, E. C., *see under* Pursey, H.

Rajaratnam, A., *see under* Webb, C. G.
Ramm, C. A., The principles and apparatus for the injection system of the Birmingham proton synchrotron 52
Ramm, C. A., R. F. Coe and T. B. Vaughan, An analysis of injection phenomena in the Birmingham proton synchrotron 102
Rayner, G. H., and L. H. Ford, The effect of humidity on the stability of inductance standards 75
Reasbeck, P., *see under* Chackett, K. F.
Richards, D. A., The magnifying powers of optical instruments 503
Richards, E. A., G. Phillips and W. K. Campe, A sensitive and stable nuclear induction head 260
Richardson, E. G., An ultrasonic apparatus for recording the height of water waves in model ship tanks 91

Riddiford, L., *see under* Batson, A. P.
Roberts, D. F. T., and E. H. S. van Someren, A simple monitor circuit for a spectrographic a.c. arc source 226
Roberts, J. E., A. J. Taylor and D. E. Woods, A mechanical Gardner mobilometer 499
Roberts, L. M., and S. J. Fray, A simple theory for solid-backed bolometers 115
Robertson, G. E. W., A micromanometer designed for recording 402
Robertson, R. E., *see under* Glew, D. N.
Rogers, E. C., E. B. Page and V. G. Harriss, A servo-mechanism for the study of self-extinction of gaseous discharges in cavities in dielectrics 7
Rogers, S. E., *see under* Plester, D. W.
Rose-Innes, A. C., and R. F. Broom, A simple desorption system for obtaining temperatures above that of liquid helium 31
Rose-Innes, A. C., *see under* Broom, R. F.

Sandels, E. G., An instrument for the measurement of salinity in estuaries 424
Sarma, N., *see under* Allan, H. R.
Sebestyén, L. G., *see under* Váradi, P. F.
Setterwall, M., A mechanical binary-decimal converter 18
Sewell, P. B., *see under* Lucas, L. N. D.
Shapiro, H., An object holder for microscopic measurements 35
Shaw, B. A., *see under* Provan, A. G.
Shipley, D., *see under* Lilburne, M. T.
Siddall, G., *see under* Allen, K. R.
Silverstein, E., and W. Slater, An alinement and co-ordinate system for nuclear emulsion stacks 381
Sims, A. L., An adaptable mechanism for converting rotary motion into a succession of linear movements 35
  A water-driven device for filling, aerating and agitating baths 320
Skertchly, A. R. B., A proportional counter tube for X-ray diffraction analysis 209
Slade, R. F., *see under* Kennedy, A. J.
Slater, W., *see under* Silverstein, E.
Smith, G. W., and R. M. Hinde, A simple scanning mechanism for X-ray diffraction 391
Smith, J. F., *see under* Payne, A. R.
Smith, M. J., and J. R. M. Vaughan, A microwave thermistor calorimeter 353
Spencer, C. W., and G. H. Bazzard, A semi-automatic pen-recorder chart analyser 228
Srdoč, D., An oxygen-quenched Geiger–Müller counter 185
Sreekantath, G. M., and A. O. Mathai, A method for comparing ultrasonic velocities in solids and liquids using a spectrometer 361
Stark, K. H., *see under* Powell, A.
Steinberger, I. T., *see under* Alexander, E.
Steinberger, I. T., *see under* Tabor, H.
Stolow, N., The measurement of film thickness with a pneumatic hypodermic needle mechanism 333
Stott, J. B., An isothermal microcalorimeter 58
Stranks, D. R., A scintillation counter for the assay of radioactive gases 1
Sucksmith, W., and S. P. Anderson, A general purpose electromagnet 234
Sullivan, N. W., Adhesives for galvanometer mirrors 362
Sumner, C. J., A reversible message register 505
Swart, E. R., *see under* Haul, R. A. W.

Tabor, H., and I. T. Steinberger, An instrument for measuring absorptivities for solar radiation 356
Tagliaferri, G., *see under* Walker, J.
Taylor, A. J., *see under* Roberts, J. E.
Taylor, H. F. W., *see under* Dent, L. S.
Taylor, R. J., An electronic analogue of the saturated vapour pressure curve of water 436
Telford, J. W., and N. S. Thorndike, Large liquid-filled plast lenses 123
Thompson, A. B., *see under* Ellis, R. A. E.
Thorndike, N. S., *see under* Telford, J. W.
Thorne, R. P., *see under* Birks, F. T.
Thuro, G., An automatic device for fixing thick nuclear emulsio layers 296
Tolmon, F. R., and J. G. Wood, Fringe spacing in interferenc microscopes 236
Tomaschek, R., Fundamental behaviour of sensitive springs 78
Tompa, H., A sensitive manostat 82
Tremlett, C. A., A method of storing mechanically fragile specimen for examination 451
Tuck, D. G., *see under* Chackett, K. F.
Turner, B. M., A constant-volume membrane, interferometri microrespirometer 263
Tyrén, H., *see under* Lovati, A.

Ubbelohde, A. R., *see under* Plester, D. W.

van der Raay, H. B., *see under* Goldsack, S. J.
van Someren, E. H. S., *see under* Roberts, D. F. T.
Váradi, P. F., and L. G. Sebestyén, A simple vacuum leak detecto using a radio-frequency mass spectrometer 392
Vaughan, J. R. M., *see under* Smith, M. J.
Vaughan, T. B., *see under* Ramm, C. A.
von Ubisch, H., Transfer of movement into a vacuum by means o twisting a copper tube 200

Waite, R. J., *see under* Anderson, A. R.
Walker, J., G. Tagliaferri, J. C. Bower and D. W. Hadley, A simpl fast-recycling cloud chamber 113
Walker, J., *see under* Hadley, D. W.
Warren, J. B., *see under* Jones, G.
Waters, W. G., *see under* Dighton, D. T. R.
Watson, J. D., *see under* Gall, D. C.
Webb, C. G., and A. Rajaratnam, A water vapour recorder fo equatorial use 132
Weir, R. J., *see under* Brown, J. F.
White, A. G., A calorimetric method of determining the energ output of radioactive materials 230
Williams, G. I., *see under* Provan, A. G.
Williams, R. W., The output resistance of a switch-dial potentia divider 451
Williams, T. F., *see under* Amphlett, C. B.
Williamson, G. K., and A. Moore, A precision high-temperatur specimen chamber for an X-ray diffractometer 107
Wilmot, P. D., *see under* Baxter, S.
Wilson, A. J. C., *see under* Hughes, J. W.
Wilson, R. N., Precision measurement of small radii of curvatur 487
Wood, J., An automatic cathode-ray oscilloscope beam brightenin device for transient recordings 203
Wood, J. G., *see under* Tolmon, F. R.
Wood, J. L., *see under* Cutting, C. L.
Woods, D. E., *see under* Roberts, J. E.
Worthington, C. R., Small angle X-ray diffraction unit 66
Wright, G. T., *see under* Hamilton, T. D. S.
Wright, R. J., *see under* Metcalfe, K. A.
Wyatt, D. G., A heart pulse amplifier and ratemeter 440
Wyllie, H. A., A gas introductor for a vacuum system 360
  A McLeod gauge for measuring a wide range of pressures 317

Yorke, S. G., Conical ground glass joint extractor 400
Young, I. R., *see under* Jones, R. V.
Young, L., *see under* Bockris, J. O'M.

PRINTED IN GREAT BRITAIN BY UNWIN BROTHERS LIMITED, WOKING AND LONDON